THE AMERICAN STEEL WORKER

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A TWENTY-FIVE YEARS' EXPERIENCE IN THE SELECTION, ANNEALING, WORKING, HARDENING AND TEMPERING OF VARIOUS KINDS AND GRADES OF STEEL

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BY

E. R. Markham

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Words are not adequate to express the debt I owe one, who, more than all others, has been instrumental in instructing, advising and assisting me along lines that have led to whatever success I may have attained.

As an humble acknowledgement of my gratitude, I dedicate this work

To My Father,

RUSSELL MARKHAM.

The American Steel Worker.

Introduction.

An experience which covers twenty-five years of actual practice, in the various branches of machine shop work, has taught the writer that much more depends on the condition of the various cutting tools used, than mechanics in general realize.

The various machines used in working iron and steel to shape have been improved, and made heavier in the parts subjected to strain, in order that heavier cuts and faster feeds might be taken to reduce the cost of production.

If a tool is doing the maximum amount of work possible for it to do, when it is used in a light machine, it would be folly to purchase a heavier, stronger machine and use the same tool in it. But it has been found in many cases that cutting tools could be made that would take heavier cuts and faster feeds than the older types of machines could carry. Consequently it has been necessary to re-design most types of machines used to remove stock, in order to bring them into shape to be used as tools, parts of machines, and other apparatus.

Competition has made it absolutely necessary that every possible means be taken to reduce the cost of an

article without reducing the quality. Where possible the design is changed so the article may be made more cheaply. And as labor is, generally speaking, the principal factor to be considered, it is necessary to reduce as far as possible the number of operations, or simplify those necessary, and so reduce the cost of the manufactured article.

If by the use of machinery especially adapted to the work to be done, it is possible to do in one operation the work which formerly required four separate operations, then the amount paid for labor has been very materially reduced, without necessarily reducing the pay of the operator. In fact it is found possible in many cases to increase his compensation, and at the same time reduce the cost per piece of work very materially.

Now, in order that improved machinery may do its maximum amount of work per day, it is necessary to have the cutting tools, fixtures, etc., made in a manner that allows them to do *their* part of the work. If a milling machine were bought and set up in a shop, and it was found that the fixtures formerly used in holding the pieces of work were not strong enough to hold them when the new machine was taking the heaviest cut possible, heavier fixtures would be made at once in order that the investment of money made in purchasing the machine might not be considered as having been thrown away. Following out the same line of reasoning, it would be necessary to make cutting tools of a design that made it possible to take as heavy cuts, and use as coarse feeds, as the strength of the machine and fixtures would allow.

While manufacturers in general recognize the im-

portance of having machines especially fitted for their needs, many times the good work stops right at this point. They are not educated to a point that makes it possible for them to comprehend the importance of having the cutting tools hardened in a manner that insures their doing the amount of work possible.

While it is often necessary to re-design cutting tools to get added strength, many times this needed strength may be had by proper hardening.

A manufacturer of a high grade tool steel, in conversation with the writer, said, if he could have one per cent. of the value of steel in this country spoiled by improper hardening, he would not exchange his income for that of the President of the United States. By the value of steel, he meant its value at the time the article was hardened. A piece of steel which cost fifty cents in the bar, may be worth many dollars when ready for hardening, and represents to the manufacturer the total cost of steel and labor.

This line of reasoning might be carried a great deal further. If a tool which is made to do a certain job is ruined, the time the machine or machines stand idle waiting for another one to be made, many times represents a greater loss than the money value of the tool. This is especially true where the time given to complete the job is limited.

If a tool is hardened in a manner that makes it impossible for it to do as much or as good work as it ought, the loss may be greater than in either of the cases before cited, yet this loss is seldom taken into consideration.

The writer's experience has convinced him that few mechanics realize the vast waste of time in many

shops, because tools are not capable of doing the amount of work possible were they properly hardened. Take for instance a milling machine cutter which runs at a periphery speed of thirty-six feet per minute, milling a mild grade of machinery steel. It is found necessary to stop this machine once in twenty working hours to sharpen the cutter, milling in the meantime five hundred pieces. A cutter is made from the same bar, and hardened by a process that makes it possible to run the tool at a periphery speed of eighty feet per minute, and it is then found necessary to grind but *once* in two hundred hours; milling in the meantime eight thousand pieces. Not only is the efficiency of this machine increased many fold, but the expense of grinding, and the necessary delay incident to stopping the machine, changing cutters and setting up, and the cost of tools per piece, is reduced very appreciably.

Does some one ask, How is this trouble to be remedied? The answer is, men must be educated to see the enormous waste going on all the time; the waste of steel, of time required to make the tools, of the time valuable equipment is laying idle, and the small percentage of work produced per machine, all go to reduce dividends, and this because so little attention is given a subject which should receive as much consideration as any one branch of machine shop work.

When the trouble is apparent, then it is necessary to find a remedy. The physician must necessarily understand the human body in order that he may diagnose diseases. If one would be a successful hardener of steel, he must understand the nature and peculiarities of steel. As a study of drugs alone would not fit one to practice medicine, neither will practice alone fit one

to harden steel, especially if new problems are constantly coming up.

At the present time when libraries are accessible to nearly every one, and books and mechanical journals, treating on steel and the proper methods of its manipulation, are within the reach of all, there is no good reason why ignorance of a subject so interesting, and at the same time of such vital importance to both manufacturer and mechanic, should be so general.

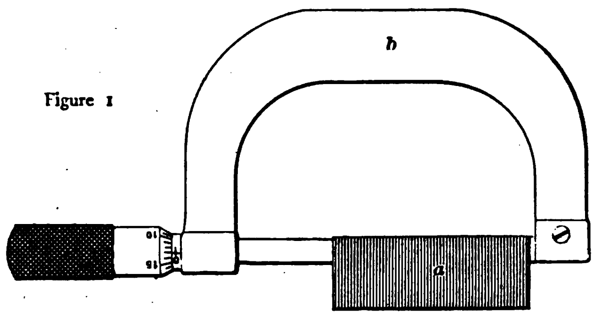
A study of the nature of steel will convince one of the importance of extreme carefulness when heating either for forging, annealing or hardening. A man who understands the effect of heat on high carbon tool steel is often amazed at the careless manner which many old blacksmiths assume when heating a piece of steel. A difference of 100 to 200 degrees of heat after the steel is red hot, does not, according to their idea, injure the steel in the least, but in reality it makes a vast amount of difference in the strength of the piece.

In some shops a man is called a successful hardener if he is fortunate enough to avoid cracking the pieces he is called upon to harden. Apparently no account is taken of the capability of the tool to perform a satisfactory amount of work. A man who devotes his attention to hardening steel in a manner to avoid cracking, regardless of the utility of the tool, is not worthy of the title of a successful hardener; he should be styled, as an eminent mechanic calls this class, *a non-cracker.* Now, it is possible to harden steel in a manner that does away with the liability of cracking, yet gives it the amount of hardness necessary, in order that it may do the amount of work expected of it.

A study of the effects of expansion and contraction

of steel in the fire and baths is necessary in order to select the proper forms of furnaces and bath, so that the best results may be obtained. Suppose a micrometer is left for some time in a room where the temperature is 40 degrees Fahr., a piece of work is placed between the contact surfaces, as shown in Fig. 1.

Figure 1



Illustrating expansion of steel.

Now grasp the micrometer by the frame at the portion marked *b*, with a warm hand; in a few seconds the metal will have expanded to a degree that allows the work *a* to drop from the gauge, thus proving that but a very small amount of heat is needed to expand the steel sufficiently so the contact points no longer touch the piece between them.

Now, if a few degrees of heat will expand steel so it can be readily observed, it is apparent that a heat of 900 to 1,200 degrees Fahr. must cause the process of expansion to be carried to a much greater extent. The amount of heat necessary to give steel, in order that it may harden when plunged in some cooling bath, varies with the make of steel, the percentage of carbon it con-

tains, and also on the percentage of other hardening elements in the steel. Jarolinech places the critical temperature at 932 degrees Fahr. (500 Centigrade) as determined by him experimentally. The lowest heat at which a piece of steel will harden satisfactorily is termed the refining heat, because the effect of the operation of suddenly cooling steel heated to this temperature is to refine the grain, making it the finest possible.

The writer does not propose giving a scientific explanation of the changes which take place in a piece of steel when it is heated to the hardening heat, and quenched in the cooling bath, but the practical sides of the question will receive careful attention.

Every man and boy working in a machine shop knows that steel heated red hot and plunged in water, will harden, but it is necessary to know how hot it must be heated in order that satisfactory results may follow. We should thoroughly understand the action of too great an amount of heat on the structure of steel, in order that overheating may be avoided. It is also necessary to have a correct understanding of the effects of baths of various kinds on steel, if it is dipped in them when red hot.

It is an acknowledged fact that the lowest possible heat at which steel will harden, leaves it the strongest This is illustrated elsewhere. Knowing this, it will be seen that an article made of steel is very much less liable to crack when hardened at a low heat, than if it were heated to a temperature which caused it to be brittle.

Commencing with cold steel, every degree of heat applied changes in a measure the size and structure

of the piece, until a certain limit is reached. Now, if a change in temperature of a few degrees changes the size of a piece of steel, the reader is asked to imagine the change in size and structure which must take place when it is heated red hot. This means a change in temperature of about 1,000 degrees, and the effect of heat on steel is to expand it, while the opposite effect is accomplished when it is cooled. The more rapidly it is cooled the harder it will be. It is indeed wonderful that a piece of steel can undergo the changes which take place in its size and structure, and remain intact. When steel is cooled in the hardening bath, the outside of course chills and hardens first, while the inside is hot and consequently soft for some little time afterward. Now, the outside, being hardened, is practically inflexible, while the inside continues to change in structure until cold. This is especially true of pieces having teeth or projections on their surface.

Understanding the fact that heat causes steel to expand, it will readily be seen that it is absolutely necessary that it should expand *uniformly* throughout the piece. If the corners and edges are hotter than the balance of the piece, then it is unevenly expanded, and consequently will contract unevenly. Now, if one part of a piece of steel contracts more than another, or not uniformly with another part, it is liable to crack from the effects of the unequal contraction; if it is not cracked when taken from the hardening bath, it is liable to crack at some future time for no apparent reason. This applies especially to large pieces, and steel having a high percentage of carbon.

The Workman.

The writer's professional experience in the various methods of working steel, brings him in contact with men of all degrees of intelligence. Some men are really skillful in the particular line they are engaged in; that is, they are very careful when heating and dipping in the bath, and get excellent results. But they do not know the difference between a steel of ¾ per cent. carbon and one of 1½ per cent; in fact, they do not know anything about percentages of carbon, and don't care; they say so in as many words. The steel they use is always the same make and temper. They have never used anything else. If they should get hold of another make, that worked differently from that they had always used, they would condemn it, saying it was no good, because it didn't act just like the steel they were accustomed to handling.

Now, if anything should happen to the steel mill making their particular brand, they would be obliged to learn the art of hardening all over again, or go out of business. When it becomes necessary, or the concern who employs these men considers it advisable, to change the steel used; or if it is necessary to have the composition changed to get some desired result, this poor fellow is all at sea. He doesn't know

what to do, and he doesn't want anyone to tell him what to do. His only cry is, "The steel isn't good for anything," when in reality it may be the best on the market. Such a man is to be pitied, but he is a very expensive man for those in whose employ he happens to be, and a very unpleasant fellow to attempt to teach anything.

Another example is the man who banks on his twenty or fifty years' experience, and considers that because he has been allowed to exist for that length of time and occupy a position as blacksmith, or hardener, that he must necessarily know it all. To him steel is steel; he treats it all alike. If there is some particular steel good-natured enough to stand his treatment, that is the only brand on the market fit to use—according to his way of thinking—and he generally has such an unpleasant and forcible personality, that he either has his say or goes where he can. He never investigates the merits of different makes of steel; simply condemns every make that will not stand his abuse.

If every man of the type under consideration advocated using the same steel, there might be a plausible excuse for looking into the merits of that particular brand, to the exclusion of every other, but you will hardly find two of them advocating the use of the same steel. I am happy to say this class of hardener is not in as great a majority as formerly; their number is gradually diminishing. It is impossible to teach him anything, because that long experience of his stands in the way; it is his only stock in trade, and he presents it every time anything is said on the subject.

Now, a long experience in any particular line of

work is a good thing for a man, provided it has been a real experience, rather than an existence, and in no line of business is it more valuable than in the working of steel, if the man has kept pace with the procession. If not, then he is no farther advanced than when he fell out of line, and as it is a law governing all our lives, that no man stands still, he must of necessity either advance or go backward. The man who has not kept pace with the progress of events, must necessarily go backwards.

Another class we meet with is the jolly, good-natured fellow, who wants to please everybody, but does not know how, and is too lazy to find out. He had rather tell a story than to keep his eyes and attention on the piece he is heating, consequently he has all kinds of luck. There is no remedy known for this chap. He is willing to be told how to do, but is too lazy to assimilate and put in practice what is told him.

A class of hardeners which are few in numbers, but who should get into some other business as soon as possible, consists of men who are practically color blind. They cannot distinguish between the various shades of red, neither can they discern the temper colors as closely as they should. Some of them are extremely intelligent, capable men, but they have missed their calling, and missed it most decidedly, because a man to be a successful blacksmith or hardener, must have good powers of distinguishing colors and shades.

There are many other classes that might be considered, but it would be a waste of time, so we will look in upon the successful hardener. There are various degrees of success, but we will consider the man

who is a success according to the generally accepted idea.

The successful hardener is one who finds out what is wanted or expected of the article he is to harden; whether extreme hardness, toughness or elasticity, or a combination of two of these qualities. He also understands the nature and pecularities of the steel he is using; he considers the fire he is to use, and the bath in which the steel is to be quenched after it is heated.

His spare moments are not spent hanging around street corners, or saloons, but in reading and studying such books and mechanical journals as treat on subjects in his line. In this way he becomes familiar with the nature of steel and knows what to do when certain conditions which are out of the ordinary arise; he gets the experience of others and his knowledge makes it possible for him to discriminate between that which will be of value to him, and that which will not.

When a piece of work is given him he studies the shape of the piece, the best method of heating and quenching, in order to get the desired results. To him steel is not simply steel, which must be treated just like every other piece of the same metal, but it is a valuable tool or piece of machinery which he takes pride in hardening in the best possible manner. If he hears of a brand that is giving some one trouble, he is anxious to get a piece of it, and experiment and find out why they can not get good results from it.

If he hears of a brand that some one claims gives extra good results when using, he is anxious to get a sample and test it, and see for himself if the steel is all the makers claim it is.

He is not above learning, takes advantage of every

opportunity to get the ideas and experience of others, especially men who have had a wide experience. To him the articles he is called on to harden represent so much money entrusted to his care, and he takes every means possible to get it out in a satisfactory manner.

Does some one ask, where do you meet such men? The writer is happy to say such men are not the exception. To be sure they are not in the majority, but the number of men who are making a careful study of this subject is really encouraging.

Steel.

Although there are many makes of steel and, in most cases, several grades of the same make, yet to the average mechanic there are two kinds of steel, viz., machinery steel and tool steel.

Machinery steel is used in making such parts of machines, apparatus or tools as do not require hardening in order to accomplish the result for which they are intended. Or, if they require hardening at all, it is simply a surface hardening, the interior of the piece being soft with a view to obtaining greater strength. This class of steel is of a lower grade than tool steel. It is softer, works more easily, both in the operations of forging and machining, and can be safely heated to a higher temperature without harm to the steel. It

resembles more closely wrought iron and is sometimes scarcely to be distinguished from it. Machinery steel is used whenever it will answer the purpose, not only on account of its being more easily machined, but its first cost is only $\frac{1}{4}$ to $\frac{1}{10}$ that of ordinary tool steel, and for most purposes where it is used, it answers the purpose as well or better.

Although it is considered advisable to group steel under two heads, as mentioned, namely, machinery steel and tool steel, yet on account of the different grades of the article under each head it will be necessary to distinguish them somewhat as they are considered under the various processes of hardening.

Tool steel is made with the idea in view that it is to be made into such tools, appliances or parts of machines as require hardening in order to accomplish the desired result. Although the term "tool steel" is applied to steel intended to be made into cutting tools, there are many makes of this article, each make differing in some respects from every other make. Not only is this so, but most makers put out tool steel of different tempers. Now, the word "temper," as used by steel makers, means the quantity or percentage of carbon the steel contains. It is low temper, medium, or high, or number or letter so and so, according to the understanding of the marks in each particular mill. The following are considered by steel makers as the most useful tempers of tool steel:

Razor temper ($1\frac{1}{2}$ per cent. carbon). This steel is so easily burnt by being overheated that it can only be placed in the hands of very skillful workmen. When properly treated it will do many times the work of ordinary tool steel when working hard metals, etc.

Percentages of carbon in tool steel.

Saw file temper (1⅜ per cent. carbon). This steel requires careful treatment, and although it will stand more heat than steel of 1½ per cent. carbon, it should not be heated hotter than a low red.

Tool temper (1¼ per cent. carbon). A very useful temper for turning tools, drills and planer tools in the hands of ordinary workmen.

Spindle temper (1⅛ per cent. carbon). A very useful temper for mill picks, circular cutters, very large turning tools, screw thread dies, etc.

Chisel temper (1 per cent. carbon). An exceedingly useful temper, combining, as it does, great toughness in the unhardened state, with a capacity of hardening at a low heat. It is well adapted for tools where the head or unhardened end is required to stand the blow of a hammer without snipping off, and where a hard cutting edge is required, such as cold chisels, etc.

Set temper (⅞ per cent. carbon). This temper is adapted for tools where the surface only is required to be hard, and where the capacity to withstand great pressure is of importance, such as stamping or pressing dies, etc.

The following also gives the steel maker's meaning of the word "temper":

Very hard	150 carbon +
Hard	100—120 carbon
Medium	70—80 carbon

In order that the reader may understand something of the significance of the terms used to designate the amount of carbon a piece of steel contains, the following brief explanation is given. A point is one hundredth of one per cent. of any element. 100 points is one per cent. A 40 point carbon steel contains forty

one-hundreths (.40) of one per cent. of carbon. The same explanation applies to any element that goes into the composition of steel. The steel is sometimes designated by the number of points of carbon it contains—as 20 carbon or 60 carbon steel. The amount of carbon the steel contains does not necessarily determine the *quality* of the steel, as the steel maker can give an ordinary low grade stock a very high percentage of carbon. This would harden under the ordinary conditions, but would be practically useless if made into cutting or similar tools.

It becomes necessary many times to procure a low grade steel having as low a percentage of carbon as possible. Then again it is advisable, where a greater amount of strength is required, to give the steel a higher percentage of carbon. This will be briefly alluded to from time to time under the various topics.

The reader will readily see from the foregoing that it is the presence of carbon in steel that causes it to harden. The amount of hardness and the degree of heat necessary when hardening depending on the quantity of carbon the steel contains. Tool steel is hardened by heating it red hot and plunging into some cooling bath. The more quickly the heat is extracted the harder the piece will be.

Tool steel has certain peculiarities which must be understood if one would be a successful hardener. The outside surface of a bar of steel, as it comes from the steel mill or forge shop, is decarbonized to a considerable depth. This is because the action of the oxygen in the air causes the carbon to be burned out of the steel at the surface during the various operations when the steel is red hot. In order that the decarbonized

portion may not give trouble, it is necessary to cut away enough of the surface to remove this portion before hardening. If a tool which is to finish ½ inch diameter is to be made out of round steel, it is necessary to select stock at least $\frac{1}{16}$ inch diameter larger than the finished tool, or the outer surface will not harden sufficiently. For sizes from ½ to 1 inch diameter, select stock $\frac{1}{16}$ to ⅛ inch larger. For sizes from 1 to 2 inches diameter, select stock from ⅛ to $\frac{3}{16}$ of an inch. For sizes above 2 inches, about ¼ of an inch should be cut off.

It is necessary when centering round steel to have the center hole very near the center of the stock, as shown in Fig. 2, in order to take off an equal quantity

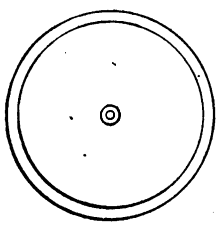


Figure 2.

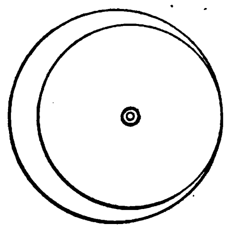


Figure 3.

Proper and improper centering.

of the decarbonizing surface all around. If a piece is centered, as shown in Fig. 3, the decarbonized surface will be entirely removed from one side of the piece and scarcely any of it taken from the opposite side; consequently, the side from which it was removed will be hard, while the opposite side will not harden, or at least will not be as hard as the other side.

So it will be very readily seen that this simple fact, which is often entirely overlooked in machine shops, is a cause of a great amount of trouble.

Tool makers, as a rule, understand this fact in regard to steel, but some one in authority, wishing to save money for the manufacturing concern, gives the job of centering to the "tool room kid," as he is termed many times. He fails to instruct him in the proper manner, the boy does not understand the nature of steel, and as a consequence, it is centered, as shown in Fig. 3.

Now, if the tool maker were given the job, he would readily see that it was centered wrong. But the spirit of economy still prevails, and the boy is allowed to rough out the piece. As a consequence, the outside surface is removed, and all traces of the eccentric centering are eliminated. The piece is made into a reamer or some other tool, and when hardened it is soft on one side, the other side being hard enough. There is no one that can be blamed but the hardener, so he, poor fellow, has to "catch it." It wouldn't be human nature to stand by and say nothing when blamed for something one didn't understand, so he, in turn, says the steel is no good.

As a consequence, the make of steel is often changed and another kind is procured, and as it is desirable to test the steel before making any quantity of it into costly tools, the tool maker is told to cut off a piece of the stock and make a reamer just like the one that wouldn't harden properly. He centers the piece, as shown in Fig. 2, turns it to size, cuts the teeth and gets it ready for hardening. It comes out all right. The steel is pronounced O. K. and a supply is

ordered. A large batch of reamers is made up and the same boy is given the job of centering and "roughing" them, and the results are the same or worse than when the former lot was hardened. Now, it is evident to every one that the hardener *must* be to blame. He hardened one reamer from this *same* steel and *it* was satisfactory. Well, the only conclusion is that he made a *mistake* when he did that *one*, and isn't on to his business, so he is nagged and found fault with until he can stand it no longer and gets out. The next man has the same results, and those in charge say, "You can't get a decent hardener now-a-days." All this trouble and expense because some one wanted the reputation of being a good manager.

Now, a boy *can* center and rough out stock and do it all right, but he must be told how and he must be watched. If a make of steel that gives satisfaction suddenly shows freaks, do not at first condemn the steel, but look for the cause. Many people have the idea that there are unaccountable mysteries connected with tool steel, and that hardening is a thing which must be attended with luck, or bad results follow. Now, as a matter of fact, if a good steel is used, the cause may be found for all troubles which occur when it is hardened, and many times they will be found to result from some penny wise and pound foolish notion.

Another peculiarity of steel is that if the position of any of its molecules is disturbed when the steel is cold, there is apt to be trouble when the piece is hardened. For instance, if a piece of steel that is to be hardened for any given purpose is cut from a bar of tool steel and it is found to be so bent that it would be impossible to turn and make straight and remove

all the decarbonized surface, the piece should be heated red hot and straightened. If it were straightened cold, then finished to size and hardened, it would be almost sure to spring. The writer has seen men at work making blanking dies for punching press work who, when they made the openings too large at any point, would take a hammer and pene the stock into the opening without heating the die. They would plane the top of the die for shear and then finish it and swear about the hardener when the piece cracked in hardening directly under where they pened. Possibly, it would not show any bad results at that time, but when the die was used, the portion referred to would crack off. Or if the punch were a tight fit, it would lift a piece of steel from the face of the die the shape of the hammer pene or of the set used.

Steels of different makes vary in their composition. A successful hardener will experiment with a *new* steel and find out just what he can do with it. One make of steel will harden at an extremely *low* heat; another make will not harden in a satisfactory manner at that heat. It requires a higher heat in order to harden it. Now, if we were to heat the first steel as hot as we were obliged to heat the other, we should ruin it, or at least harm it. For this reason it is not advisable, generally speaking, to have a half a dozen different kinds or makes of steel around a shop, unless someone knowing the nature and peculiarities of each is to do the hardening. And even then trouble will follow unless a ticket accompanies each tool stating the kind of steel, and this in the ordinary machine shop would lead to endless confusion.

A steel which gives satisfactory results should be

selected and then used until convinced that something better is to be had. The judgment of an experienced hardener is not always to be relied upon as to the best brand of steel for a particular purpose. It may be that he has had excellent results with a certain brand because he has methods of hardening particularly fitted to that brand of steel; but it may be true that were he to change his methods to adapt them to another steel, much better results would follow.

The writer was at one time brought in contact with a hardener whose complaints in regard to the steel furnished had caused the superintendent of the shop to change the make of steel several times. Each time a new steel came into the shop the result was the same, until finally by the advice of one of the steel manufacturers several tools similar to those previously hardened with unsatisfactory results were made from each of the condemned steels and given to a man who was considered an expert hardener. When they were hardened and returned they were all found to be in a satisfactory condition, not a crack visible in any of them. They all gave good satisfaction, proving that the man rather than the steel was at fault.

Almost any of the *leading* makes of steel in the market will give good results if treated properly, but the same treatment will not answer for all makes. Some makes are more satisfactory than others for certain purposes, but better results may be obtained from most of them than is often the case.

Steel may be purchased in bars of various shapes. The more common shapes are round, square, flat and octagon. If steel is to be cut from the bar and machined to shape, it is advisable to purchase bars which

allow of machining to the desired shape, at the least expense and with as little waste of material as possible. Always remember that it is necessary to remove the decarbonized portions previously mentioned.

If a tool which is to be cylindrical in shape is to be made, use a piece of round steel. If an article which is to be finished square, use a piece of square steel, etc.

Steel of the same quality and temper is furnished in all the common shapes on the market. It was formerly considered necessary, if best results were desired, to use octagon steel when making cylindrical pieces of work,. but now all steel makers claim to make round steel of exactly the same quality as the corresponding sizes of octagonal shape, and the experience of every mechanic who has tested the two under similar circumstances substantiates the claim.

The steel maker puts on the market steel of different tempers, but he advocates the use of the particular temper which he considers best adapted to the work in the individual shop. As a rule he does not make any mention of any other temper, because he knows that if steel of several different tempers are kept in stock, that in all probability the labels will be removed in a short time and any distinguishing marks be thrown away. Then no one in the shop will know one temper from another, and when a piece of ⅞ per cent. carbon steel is made into a shank mill or similar tool, and a piece of 1½ per cent carbon steel is made into some tool that must resist the action of heavy blows, trouble will follow and the steel be condemned. For this reason it is considered advisable to advocate the use of a temper that will give satisfactory results when put to most uses. But the fact remains that

steel, in order to give best results, should contain the proper percentage of carbon for use on the particular job.

In shops where detail is followed very closely, the steel is kept in a stock-room, each different temper by itself, and so marked that there is no danger of it getting mixed. Much better results are then obtained, provided a competent man does the hardening, than if one temper was used for everything. But in a shop where there is only one rack, and sometimes no rack, the stock, machinery steel, tool steel, and everything else is kept on this one rack, or in a pile on the floor, it is not advisable to have steel of different tempers lying around, or results anything but satisfactory are sure to follow.

Percentage of Carbon Necessary to Produce Desired Results.

In the first part of this section is given a table of percentages of carbon present in steel for various purposes. This table is generally accepted as a guide to those desiring steel for any given purpose, and, generally speaking, it is safe to use stock of the tempers given, but modern competition has made it necessary to harden steel harder and yet have it able to stand more than was formerly the case. When these conditions prevail, it is necessary many times, especially in the case of cutting tools, to use steel having a higher percentage of carbon than is given in the table.

When steel containing a higher percentage of carbon is used, then extra care must be observed when heating. For the operations of forging, annealing, or

hardening high carbon steels should not under any circumstances be given to a careless workman, or to one not thoroughly familiar with the effects of heat on steel of this character.

When high carbon steels are used and treated properly, they will do more work than steels containing a lower percentage, but unless they are to be handled by a competent man, they generally prove to be a very unsatisfactory investment.

When long articles which are to be hardened are made of tool steel, the writer has had excellent results by taking the steel as it came from the bar, or after it was roughed out for annealing, or even after it was forged in the smith's shop, by heating it to a forging heat. Then, standing it on end on the anvil, or on a block of iron on the floor—if it were long—and giving it one or more blows on the end with a hand hammer or sledge; the weight of the hammer depending on the size of the piece. This operation is sneered at by many expert steel workers, but the writer's experience convinces him that better results will follow when the piece is hardened, if this precaution is taken, the tendency to spring is apparently greatly reduced. Should the piece be bent by the operation, it should be straightened while red hot, because if straightened cold, it most surely will spring when hardened.

The writer has no intention of advertising any make of steel, as he does not believe any one make is best for *all* purposes, but experience has convinced him that some makes of steel give better results for certain purposes than others, also that some makes are better adapted for "all around" use than others.

If a party is using a steel with unsatisfactory

results, it is advisable to take measures to ascertain whether the trouble is in the steel, or in the method of working it. The writer has seen one of the best steels on the market condemned and its use discontinued, because the workman who did the hardening had been accustomed to a steel containing a lower percentage of carbon. The steel he recommended was adopted, the results so far as hardening were concerned were satisfactory, but the toois did not produce nearly the amount of work they should.

After a time, the services of an expert were sought. He advocated the use of the very steel they had discarded. A tool was made from it, the expert hardening the tool. When put to actual use, it proved itself capable of doing many times the amount of work between grindings that could be obtained from low carbon steel.

The hardener, like a sensible man, allowed the expert to instruct him in the proper methods to pursue, with the result that he became one of the best hardeners the writer has ever had the pleasure of meeting.

A steel should never be selected because it is *cheap*, because it often happens that the steels which sell for the least money are the dearest in the end. It is possible to put $100.00 worth of work on a piece of steel costing 25 cents. Now, if the tool was found useless when hardened, then $100.25 has been expended in vain. On the other hand, if steel adapted to the purpose had been used, and it had cost 50 cents, there would have been a clear saving in money of nearly $100.00. This is not an exaggerated comparison, as such cases are frequently met with by the writer.

On the other hand, it is folly to pay 75 cents a

pound for steel, when 16 cents will buy one exactly suited to the job. Good steel is cheaper at any price it would be apt to bring in the open market, than steel not adapted for the purpose would be if it were a gift. A steel not adapted to the purpose is *dear at any price.*

The writer has had charge of tool rooms employing large numbers of tool makers, and experience has convinced him that it is a saving of money in every case to test every bar of tool steel received into the shop that is to be made into tools.

If the steel is kept in the stock-room, the stock keeper can—when the hack saw, or cutting off machine is not in use—cut a piece from the end of each bar, stamping the piece cut off and the bar alike. These pieces can be given to an experienced hardener, to heat them to the proper hardening heat, and quench them in a bath of water or brine. After they are thoroughly dry, break as near across the center as possible, examining the center of fracture for pipes. A pipe is a cavity which of course makes the bar unsound. It may run the entire length of the bar. If a bar having a pipe is discovered, the steel maker will gladly replace it with a sound bar. Any make of steel is liable to have cavities of this kind, although the inspector at the mill generally discovers it in the ingot, thus preventing it being made into bars; but it sometimes escapes even the most careful inspection.

If a tool costing $50.00 were made from a bar that was piped, it would in all probability go all to pieces in the bath when hardened, unless the tool were of a character that allowed the piped portion to be removed. It is safer, however, to inspect the bar before any costly tools are made from it. If the bar proves

sound, the grain should be examined; if this is fine, and of the proper appearance, it may be tested for hardness with a file.

If the piece proves to be all right, the bar may be stamped O. K. or given some distinguishing mark; should it prove otherwise, the manufacturer should be notified and the steel returned to the mill.

This system of inspection may seem like a needless waste of money, but the cost of one tool which is of no use when finished, would pay the necessary expense of testing all the steel used in a machine shop of the ordinary size in five years.

When a tool is required to do extra hard work, that is, cut hard stock, or run at a higher speed than is ordinarily employed in the shop, it is advisable to get a steel having a greater percentage of carbon than the steel used for tools for ordinary work. When high carbon steels are bought, they should be distinctly labeled or stamped, and kept by themselves away from the rest of the steel, because if the identity of the piece is lost, it is liable to be made into tools and hardened without the hardener knowing that it differs in composition from the steel ordinarily used. As a consequence he would heat it to the same temperature he was accustomed to give the steel regularly used, and it would in all probability be cracked from the heat which was higher than was necessary.

Methods of Heating.

The method employed when heating steel for any particular purpose depends on the facilities furnished by the individual shop. As it is not, generally speaking, the office of the hardener to purchase the equipment of the shop; but to use such equipment as may be furnished him, it is necessary that he adapt himself to circumstances as he finds them. The successful man is one who makes the best use possible of the equipment furnished him.

If there are but a few tools to harden, and they are of a character that could be treated in a satisfactory manner in an ordinary blacksmith's forge, it would not be considered advisable to purchase a costly furnace, even though it were known that the work could be done more cheaply per piece, because the limited number of pieces would not warrant the extra outlay of money for equipment.

On the other hand, if work was to be done in large quantities, it would be wise to procure the necessary equipment to do the work in a satisfactory manner at the least cost possible. If the total amount of hardening done in a shop in any one year was 6 or 7 diamond point turning tools and 2 or 3 side tools, it would be folly to invest several hundred dollars in a muffle furnace and an elaborate system of baths. But if the product of the shop was several hundred taps, reamers or

similar tools per day, it would not be considered good business policy to heat them for hardening in an ordinary blacksmith's forge. It would not be possible to do the work as cheaply, neither would it be done in as satisfactory a manner as though apparatus especially adapted to this class of work were used.

But, as previously stated, the hardener should make the best possible use of apparatus furnished him. If obliged to use a blacksmith's forge for heating steel either for forging or hardening, he should see that his fire is clean and that it is high enough above the blast inlet so no jet of air can strike the heated steel.

It is possible to heat comparatively small articles in a satisfactory manner in an ordinary forge by using care in regard to the size and condition of the fire and the location of the piece of work in relation to the blast inlet.

It is always advisable to build a fire large and high enough so that the portion of the piece being heated will be covered to a considerable depth by the coals. Otherwise the action of the oxygen in the air would cause the carbon to be burned out of the surface of the steel, leaving it decarbonized; in this condition it cannot harden.

If the cold air from the blast strikes heated steel, it causes it to crack, particularly if there are teeth or projections, as these are more susceptible to the action of heat and cold than the heavier portions. The steel would expand from the action of the heat, the air striking the projections would cause contraction, and the repeated expansion and contraction would cause the steel to crack.

If large pieces are to be hardened, a large high

fire should be built, as a low fire in a forge having a tuyère—blast inlet—of the ordinary size would not be sufficiently large to heat the piece uniformly. It is always advisable when heating large pieces to use a fire of new coals if charcoal is used as fuel, as coals which have been used for some time are burned to the extent that the fire is dead unless considerable blast is used, in which case the result would be a lot of cracked work.

Charcoal is generally considered the ideal fuel to use when heating tool steel. As it is a form of carbon, it is generally given credit for imparting carbon to the steel heated in it. Now, this is the case, if *low* carbon steels are packed in a tube or box with a good quality of charcoal, away from the action of the fire and air, and run for a considerable length of time. Carbon will then be absorbed by the steel. Before the process of making crucible steel was discovered, iron bars or rods were packed in tubes with charcoal and run for a sufficient length of time to charge the iron with carbon, thus making a union of iron and carbon, or steel, as it is familiarly known. This process is known as "cementation."

It does not seem probable that a piece of tool steel, high in carbon would absorb any extra carbon in the brief time it was exposed to the action of fire, in heating for hardening. On the contrary, if a piece of high carbon steel is heated in this manner, it is apt to lose some of the carbon at the surface. For this reason, a piece of high carbon steel is not so liable to have surface cracks if heated for hardening in a charcoal fire. But from experiments, it can, I think, be truthfully claimed that a piece of 1.5 per cent. carbon steel will

not be as hard on the surface if heated in a charcoal fire, as if heated in a fire burning coke.

But if steel must be heated in a fire, exposed to the action of the burning fuel, it is advisable in most cases to use charcoal, because it does not contain impurities injurious to the steel.

On the other hand, high carbon steel will not be as hard on the surface if heated in a charcoal fire, as if heated in some form of furnace where the article is not exposed to the action of the burning fuel, and as most of the other fuels contain impurities injurious to the steel, it is best to heat in a manner that removes it from the action, not only of the burning fuel, but also from the action of the air. In order to accomplish the desired result, the article may be placed in a tube or iron box, or a muffle furnace may be used.

If many pieces are to be hardened, it is advisable to procure a furnace especially adapted to the class of work. The neatest, most easily managed furnace, and the one which gives as good satisfaction as any, is a form made to burn illuminating gas as fuel. These can be procured of almost any size. A very satisfactory style of this type is known as a muffle furnace, from the fact that the piece of steel to be heated is placed in an oven or muffle. The flame circulating around the muffle heats it to any required degree of heat. The steel is heated by radiation, consequently it is not subjected to the injurious effects of the products of combustion; and as the door may be closed, there is little danger of oxidation of the heated surface. If the furnace is not provided with some means whereby the work being heated may be readily observed without removing the door, it is advisable to drill one or two

one-inch holes in the door, covering them with mica. These furnaces are by far the most satisfactory for general use of any form the writer has used. Figs. 4 and 5 represent two styles of these furnaces. If it is not considered advisable to purchase a furnace of this description and one is to be made on the premises, it is possible to make a very satisfactory furnace quite cheaply. If large or long pieces are to be heated and a furnace is to be made of a type where the steel is placed in contact with the fuel, it is advisable to use charcoal, as either coke or coal do not furnish a satisfactory means of heating under the circumstances mentioned. The grate should be made the size of the

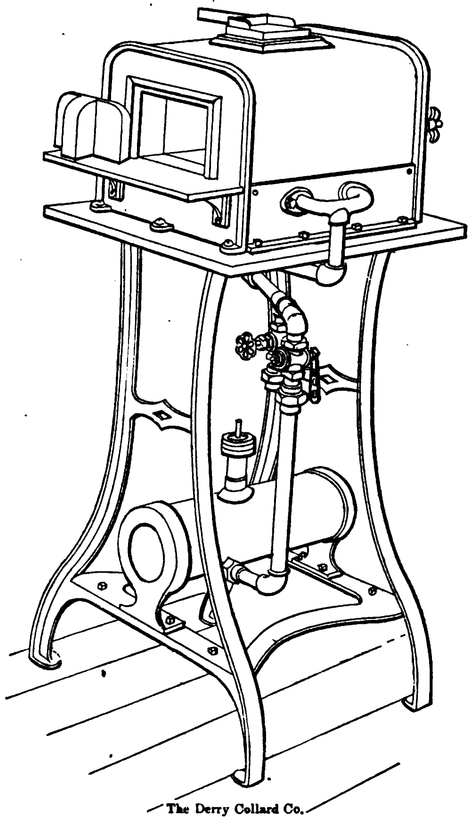


Figure 4. Muffle furnace for hardening.

inside of the furnace, as in this way a uniform heat may be maintained in all parts of the furnace, and it will not be necessary to use a blast. A natural draft will be found sufficient.

Fig. 6 shows a furnace of the type mentioned, the dimensions depending on the size and character of the work to be heated. A damper should be placed in the smoke pipe in order to check the fire if there is danger of its becoming too hot. This damper should not be of the type usually put in the pipe of a coal stove, as these dampers are made with a hole to allow for the escape of gas. It is not desirable to have this hole in the damper, as it is impossible to check the fire on a windy day. The lower door must also be furnished with a damper, in order to furnish draft when desired. It is possible with this furnace to do very excellent work.

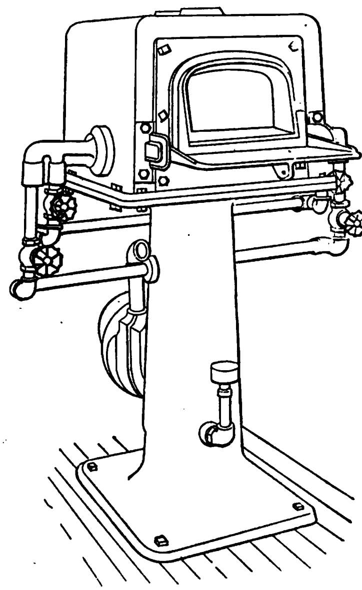


Figure 5. Muffle furnace for hardening.

If it is desirable to build a muffle furnace, one may be made to use either charcoal, coke, or hard coal as fuel by taking the one represented in Fig. 7 as a model, and changing the design to meet the require-

ments. The interior of the muffle is represented by A, B is the fire box, C the ash pan. The heat and smoke passing up from the fire box follow the direction of the arrow passing under the muffle and out of the smoke pipe at D. A damper should be placed in the smoke

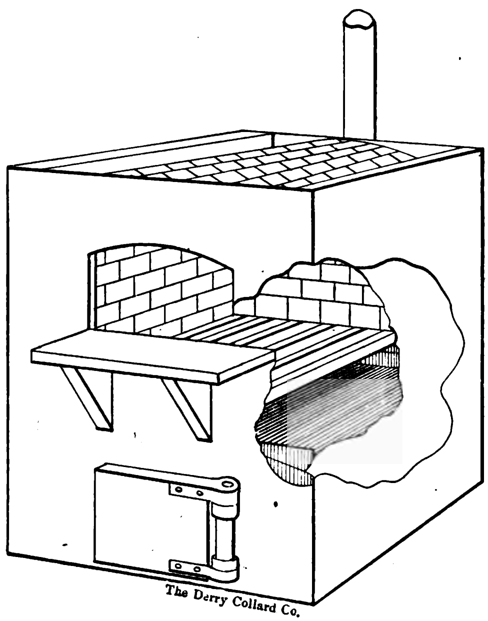


Figure 6. A "home-made" furnace.

pipe and one in the ash chamber door. By means of these dampers the draft can be regulated very nicely. This form of furnace works very nicely in heating dies and similar work.

When small articles are hardened in large quantities a furnace may be made of the design shown in

Fig. 8, where *a* represents the fire box which burns hard coal, charcoal or coke; *b* the ash box; and *c* the chamber for heating the work. The front plate has a number of holes corresponding to the number of tubes it is considered advisable to heat at a time. The tubes are made by taking a gas pipe, plugging one end as

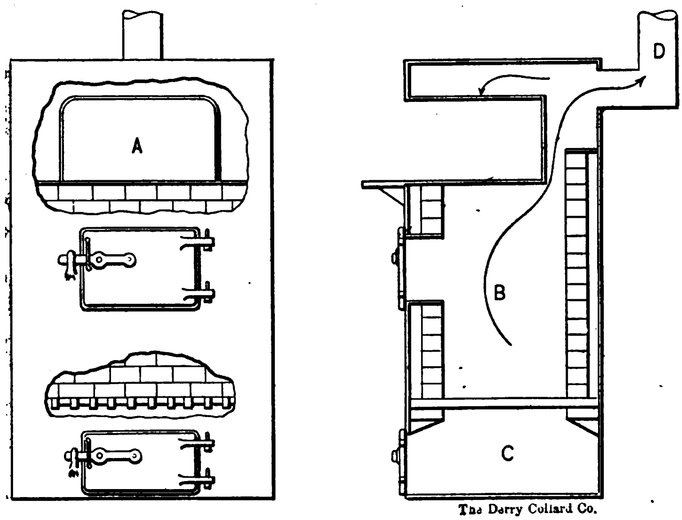


Figure 7. A "home-made" furnace for burning charcoal, coke or hard coal.

shown as Fig. 9, the other end being left open. A number of pieces of work may be placed in each tube and the tubes placed in the openings. The tubes at the bottom will heat more quickly than those at the top, so it is advisable when a tube in the bottom row is taken from the furnace to fill its place with one from one of the top rows. The tubes as they are filled may be placed in the top rows and allowed to heat gradually

and later removed and placed in the lower row. By following this plan it is possible to heat the work

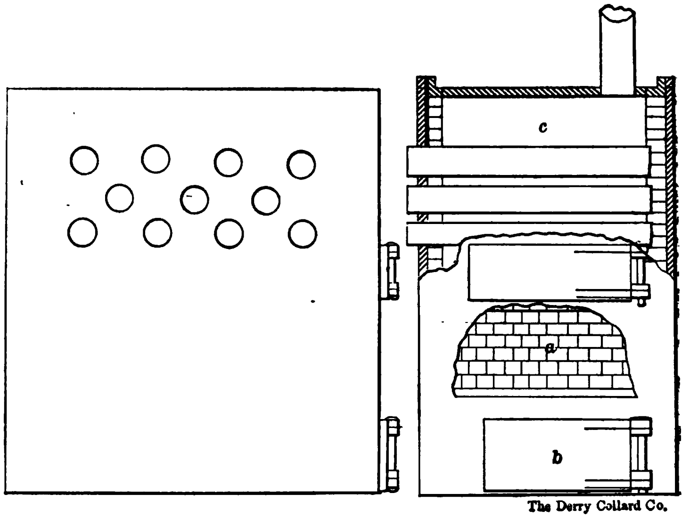


Figure 8. A "home-made" furnace for heating small pieces.

gradually and yet harden a large amount of work in a given time. The tubes should be turned occasionally in order to insure even heating and satisfactory results.

When but a few small pieces are to be hardened

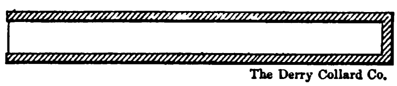


Figure 9. Construction of tubes in "home-made" furnace.

a gas blast of the form shown in Fig. 10 answers very nicely. If the pieces are of a size that guarantee their

heating quickly it is safe to hold them in the flame, having a piece of fire brick to reflect the heat. By this means the heat is utilized to much better advantage than if nothing were placed back of the work. It

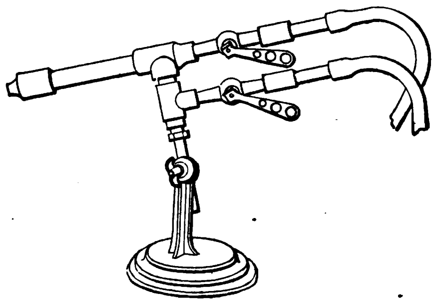


Figure 10. Gas blast for heating a few pieces.

is possible by forming a cavity in the brick or making a small oven as shown in Fig. 11 to heat a much larger piece of work in an ordinary blow pipe than would otherwise be the case.

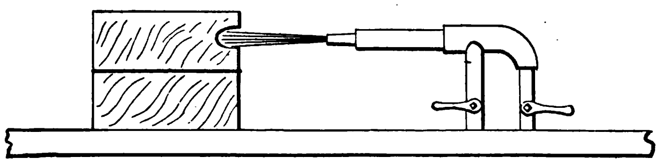


Figure 11. Another form of gas blast for heating

A crude but satisfactory method of economically heating small pieces is furnished by the idea presented in Fig. 12, in which case a small oven is built of fire brick, or a casting of the desired shape may be

obtained. In either case a flame from gas blast should enter at one or both sides through holes provided.

Small articles may be heated by using a Bunsen

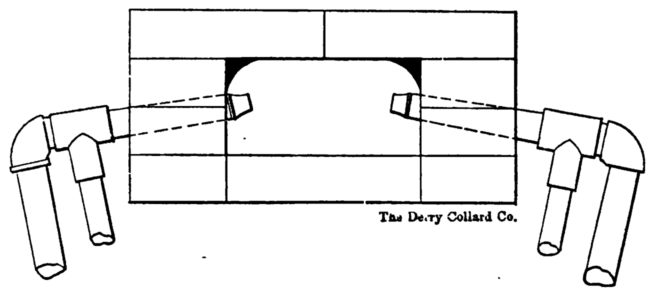


Figure 12. Small "home-made" gas blast oven.

burner, as shown in Fig. 13, which can be applied to a gas pipe in place of the ordinary burner, or may be connected by means of a piece of rubber tube. When using a burner of this description the work can be heated more readily if a piece of sheet iron is placed over the burner at the proper height, the article to be heated being placed beneath this, the sheet metal reflecting the heat and thus increasing its utility.

It is also possible by means of a blow pipe to heat very small articles sufficiently for hardening by means of an ordinary gas jet or the flame of a spirit lamp, as shown in Fig. 14. This is an expensive method when work is heated in quantities, but answers very nicely for one or two pieces.

When heating for forging or any work where the outside of the steel is afterwards to be removed it is

advisable to use a form of furnace where the direct heat of the fire comes in contact with the steel, as it is much more economical and is, generally speaking, a quicker method than heating in a muffle furnace. It is advisable many times when heating large pieces of steel for hardening, to use a furnace, as described, on account of economy. In case

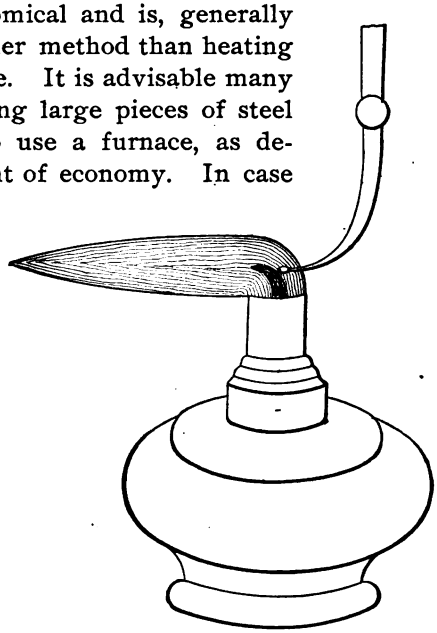


Figure 14. The blow pipe way of heating.

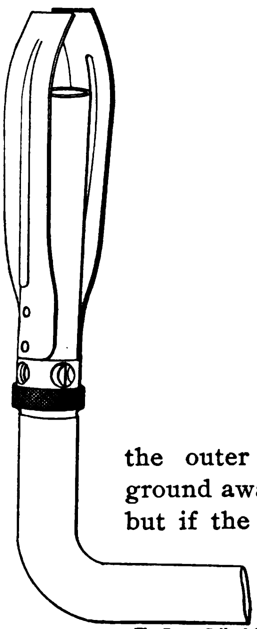


Figure 13. **Bunsen burner, for heating small articles.**

the outer decarbonized surface is to be ground away, the results will be satisfactory; but if the outer surface must be hard, then it is necessary to protect the surface from the action of the products of combustion. This may be accomplished by several different methods.

Covering paste, and how to make it.

One method is to place the portion of the piece, which must not be decarbonized, in a box with carbonaceous materials—as charcoal or charred leather—and subject to heat until the piece has reached the desired uniform temperature, being careful that the part which is exposed to the direct heat of the fire does not get over-heated.

Another method which is used when an article must be hard on all its surfaces is to cover the piece with a carbonaceous paste, consisting of the following ingredients:

Pulverized charred leather........	2 parts.
Fine family flour..	2 "
Fine table salt....................	1 part.

Mix thoroughly while in a dry state. Water is then added slowly to prevent lumps; enough water may be added to make it of the desired consistency, which depends on the nature of the work and the length of time it must be exposed to the action of the fire. If the articles are small and will heat to the proper temperature for hardening in a few minutes, it should be of the consistency of varnish. If, however, the pieces are large and require considerable time for heating, it must be made thicker.

Various substances are heated red hot in crucibles or iron dishes, and pieces to be hardened are heated in them. These exclude the air and so prevent oxidation and decarbonization of the surface of the steel. Among the substances used are lead, tin, glass, cyanide of potassium, a mixture of salt and cyanide of potassium.

Lead is heated in a crucible in a furnace of the forms shown in Figs. 15, 16. It furnishes a very excel-

lent means of heating work which is hardened in large quantities. When making furnaces to heat lead red hot for use in hardening steel, some means should be provided for carrying off the fümes of the lead, as they are very injurious to the workman. They are especially hard to dispose of, as they are heavier than the atmospheric air; consequently cannot be disposed of as readily by means of a ventilating shaft as other fumes. It is necessary to furnish a pipe connected with an exhaust fan. This pipe may be at the back of the furnace instead of over it, as is generally the case when gases or smoke are to be carried off. It should not be arranged in a manner that will cause the surface of the lead to become cooled by a current of air passing over it.

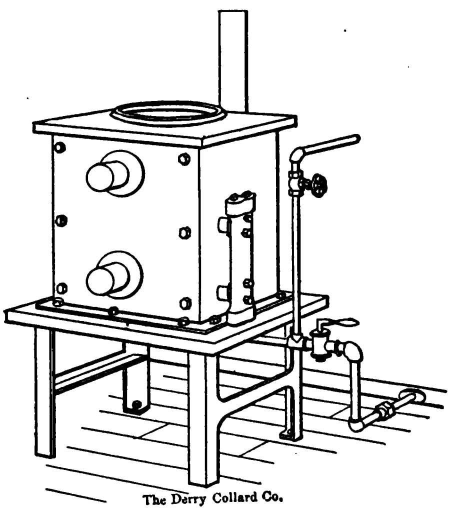


Figure 15. Lead hardening furnace.

If illuminating gas can be procured at a reasonable rate, it furnishes an ideal method of heating a crucible of lead. Furnaces burning illuminating gas can be procured of a size and shape adapted to the work to be done. If, however, it is considered advisable to make a furnace for this purpose, one may be made which

will give good satisfaction. It can be made to burn oil, coal, charcoal or coke. If oil is the fuel to be used, it is advisable to install a system especially for this method, and as circulars and full explanations can be

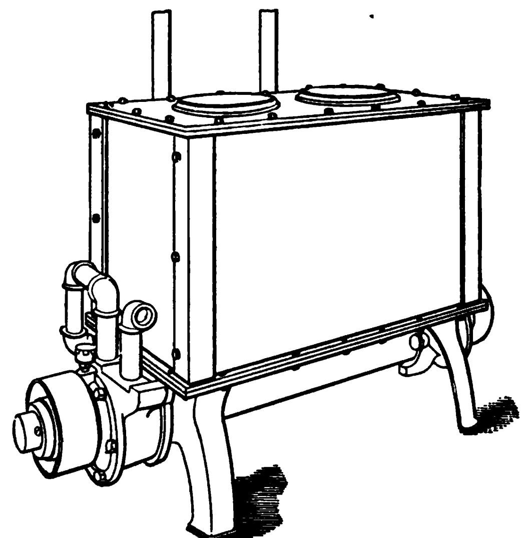
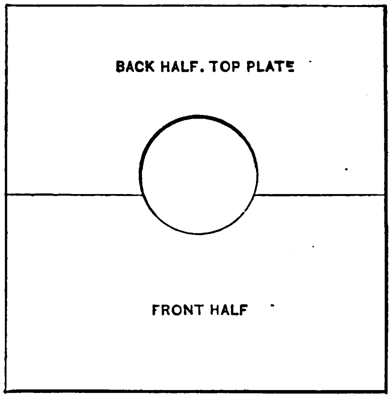


Figure 16. Lead furnace for hardening.

procured from manufacturers who make these outfits, it would not be wise to go into their details here.

If it is considered advisable to make a furnace burning charcoal, hard coal or coke, the design shown in Fig. 17 may be used or changed to adapt it to these fuels. The outer shell may be made of cast iron, although it may be possible to procure an old



boiler, which can usually be bought very cheaply. A piece the desired length may be cut from this, that answers the purpose very nicely. A round grate and the necessary frame to support it may be procured from a stove dealer. The form of grate

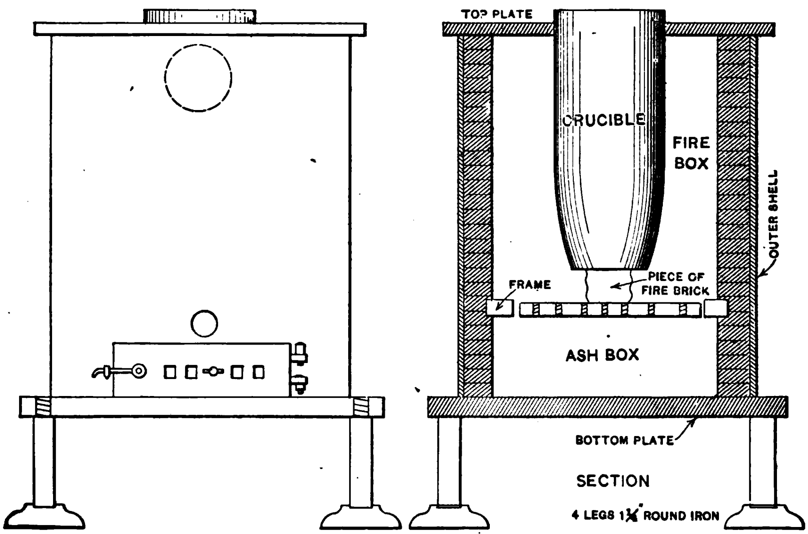


Figure 17. Coal, coke or charcoal furnace for lead heating.

used in the ordinary cylinder parlor stove will answer every purpose. The frame should be attached to the shell or blocked up from the bottom of the ash box, to allow the grate to be turned in dumping the contents of the furnace. The interior of the furnace may be made of circular fire brick, which may be supported by the slab which forms the base or bottom of the ash box and designated as the bottom plate. In case fire brick are used, the grate frame may be built into the brick work as shown. If, however, a stove lining of the desired size can be procured, the bricks need extend only up to the frame, the lining extending from the frame to the top of the shell. It is necessary to cut an opening in the ash box in the front of the shell. This should be covered with a swinging door, containing a sliding damper. This door is necessary in order to remove the ashes.

A smoke pipe must be provided to carry off the smoke and gas from the fire. This should be connected with the shell at the top on the back side of the furnace. Over the top of the furnace must be placed a plate, having a hole in the center about one half inch larger than the size of the crucible to be used. This plate should be cast in two pieces, having more than one-half of the hole in the part that goes at the back. The smaller or front half may be moved forward, thus affording an opening to feed the coal to the fire. The object in having more than one-half the opening in the back part of the cover is to prevent the crucible from tipping over when the front plate is removed, when there is not sufficient coal in the furnace to support it. It is necessary to place a piece of fire brick in the center of the grate for the crucible to rest on in order

that the fire may be beneath it. The smoke pipe should be provided with a damper, to enable the operator to properly control the fire. This form of furnace gives best satisfaction when hard coal is used as fuel.

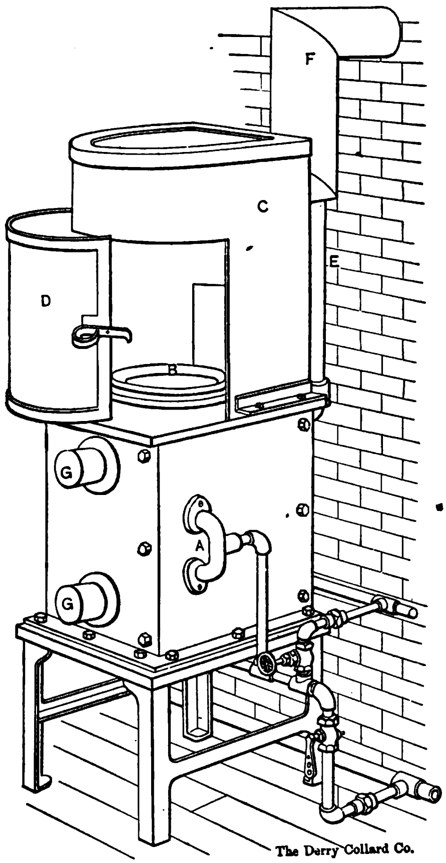


Figure 18. Furnace for heating in cyanide of potassium.

Red-hot cyanide of potassium is used with excellent results in heating tools for hardening. It not only heats the steel uniformly, but, being lighter than steel, the latter sinks in the fluid, thus effectually excluding the air from the surface of the steel. It also has the effect of making the surface somewhat harder than it otherwise would be, without making the steel more brittle.

It should be borne in mind that cyanide of

potassium is a violent poison, and great care should be exercised in its use. Not only is it poisonous when taken into the stomach, but the fumes are highly injurious to the workman if inhaled. However, if furnaces are properly designed and set up, the fumes may be disposed of in a manner that does away with this trouble.

In Fig. 18 is shown a form of furnace made especially for use in heating in cyanide of potassium. The fuel used is illuminating gas, the products of combustion passing up the pipe E to the main pipe F which also conveys the fumes of the melted cyanide into the chimney or ventilating shaft. The burners enter the furnace at A and heat the crucible B, which contains the cyanide. A hood C, which is provided with a door D, keeps the fumes from entering the room as they are conveyed into the pipe F. The lighting holes G G are closed by the plugs shown when the fire is well under way.

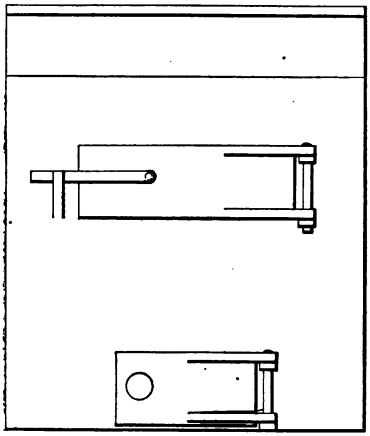
When a comparatively small number of small pieces are to be hardened, it is possible to heat the necessary amount of cyanide in a small iron dish in an ordinary forge. The pieces may be held in this until the desired effect has been accomplished, when they may be quenched.

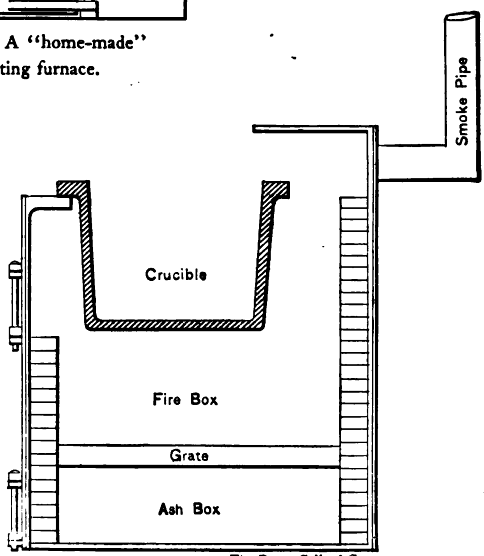
As the work heated in this manner is usually hung from the edge of the crucible by means of wire hooks, it is generally considered advisable to use a square crucible rather than a round one when work is done in large quantities.

When a furnace is to be made for this purpose, the form represented in Figs. 19-20 will be found to give good results. This furnace burns hard coal. The cruci-

ble which is made of cast iron is square in shape and hangs from the flange, which is cast around the upper edge. The top of the crucible is below the top of the back of the furnace. An opening into this allows the fumes to escape into the chimney.

A quantity of salt is placed in a crucible and heated red hot. To this is added cyanide of potassium until the steel heated in it shows the proper amount of hardness. This method is used by manufacturers of taps and similar tools, who claim excellent results by its use. The same general





Figures 19-20. A "home-made" cyanide heating furnace.

remarks apply to this method as to heating in cyanide of potassium.

Glass heated in a crucible until it is red-hot is the means used by some watch makers to heat the hair springs of the watches. It is claimed that the nature of steel heated in this manner will not change in the least.

Very little attention is paid in most shops to the location of the forge or furnace used in heating steel; generally any out-of-the-way place is selected. If there is any portion of the shop that cannot be utilized for anything else, it is given up to this purpose.

The fire for heating steel should receive more consideration, so far as location is concerned, than almost any other part of the equipment. It should never be located where the direct rays of the sun or any strong light can shine in it, or in the operator's eyes, for uneven results will surely follow. It should never be located in or near a window, neither should the roof be constructed with skylights which allow any of the sun's rays or any strong light to enter the portion of the room where the furnace is located.

An ideal place for the location of a furnace used in heating steel for hardening, is in a room so constructed that no rays of sunshine or direct light can enter it.

It is extremely important that due consideration is given the subject of ventilation. Some means should be provided whereby pure air can be freely supplied without creating drafts, which would cause the operator, who is perspiring freely, to take cold. The room should be so located that it will not be damp, or the health of the workman would be hazarded.

Too often in the past the precautions noted have

received very little consideration, because those in charge did not realize the importance of a properly equipped or located room in which to do this class of work.

Heating Tool Steel.

Tool steel is very sensitive to the action of heat. A slight difference in temperature after a piece has reached the proper hardening heat will be noticeable in the grain of the steel. When heating for hardening, the lowest possible heat that will give the desired result should be used. The amount of heat necessary to produce this result depends on the make of the steel, the percentage of carbon it contains, the percentage of other hardening elements that may be in the steel, the size of the piece, and the use to which it is to be put when hardened—all these must be taken into consideration. A steel low in carbon requires a higher heat than a piece of high carbon steel in order that it may be as hard. A small tool does not require as much heat as a larger one of the same general outline. A tool with teeth or other projections will harden at a lower heat than a solid piece of the same size made from the same bar of steel. There is a proper heat at which a piece of steel *should* be hardened in order to produce the best results, but *this heat varies*, as previously explained.

If two milling machine cutters were made from

two different makes of steel the writer has in mind, and were heated in a manner that would give excellent results in the case of one, the other would not harden satisfactorily. Now, were the operator to heat both to the proper hardening heat for the other make, the first one mentioned would be unfitted to do what was expected of it. Either make of steel would give good results if heated to its proper heat.

The commonly used expression of degrees of heat which tool steel should receive is a cherry red. The writer cannot dispute the appropriateness of this term, but cherry red is a varying color when applied to the hardening heat of tool steel, and also when applied to cherries. Mr. Metcalf, in his work on steel, styles this heat as the refining heat, and this seems to express the idea nicely.

Steel should be heated to a temperature that, when hardened and broken, the fracture will show the grain to be the finest possible, and the steel will be hard. Now, if we heat a piece from the same bar a trifle hotter and break it, the fracture will show a coarser grain. The hotter the piece is heated, the coarser the grain becomes; and the coarser it is, the more brittle the steel is. While, to be sure, steel heated a trifle above the refining heat will be somewhat harder than if heated to the refining heat, yet the brittleness more than offsets the extra hardness; and if it is to be used, it will be found necessary to draw the temper in order to reduce the brittleness to a point where it is practical to use the tool.

After taking the necessary means to reduce the brittleness as described, an examination of the tool will reveal the fact that in drawing the temper we have

softened the piece to an extent that it is not as hard as the piece hardened at the refining heat. Neither will it do anywhere near the amount of work, as the grain is open and when the pressure is applied in the operation of cutting, the surface caves in because of the open grain. The surface has not the backing it would have, were the grain close or fine.

A method which the writer has used in his experiments and also in demonstrating the effect of heat on the grain of steel is to take six pieces of steel that can

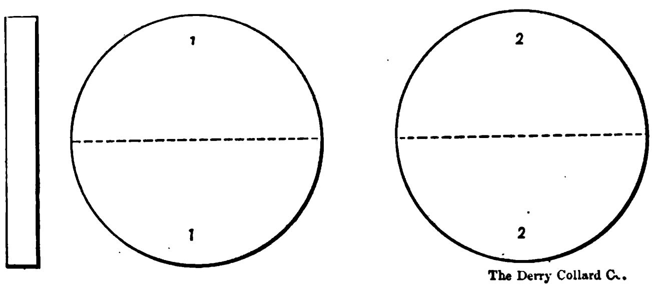


Figure 21. Test pieces.

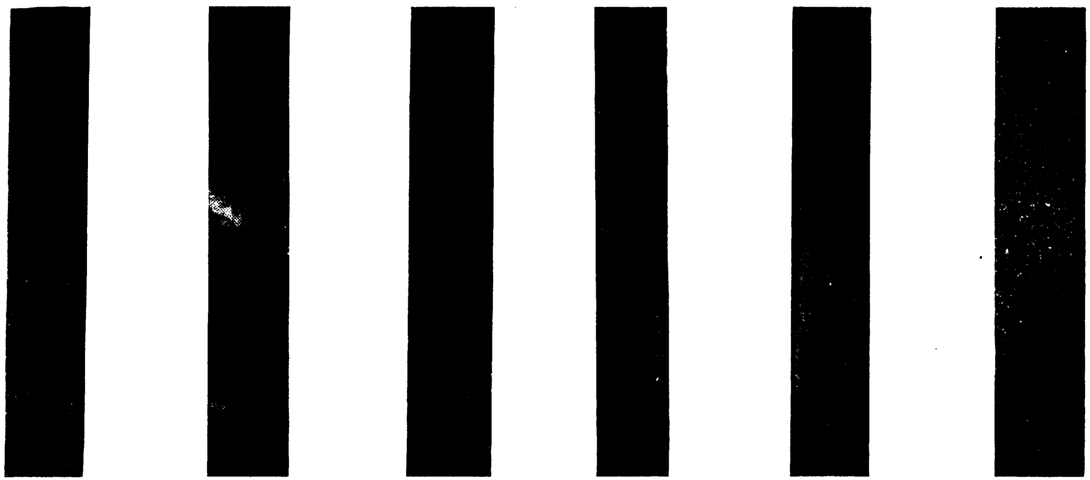
be readily broken. Cut the required number from a bar 1 inch to 1½ inches diameter, having the pieces about $\frac{3}{16}$ of an inch thick. Now heat the pieces one at a time in a furnace so situated that no rays of the sun or any strong light can shine either into the fire or into the eyes of the operator. It is advisable to have the furnace located in a room that can be darkened so that it is neither light nor extremely dark, but it must be uniform throughout the experiment. Now heat one piece until it shows somewhat red, yet a certain black is discernible in the center of the piece. Dip into the bath and work it around well; leave until cold. Now

heat another piece until it shows the lowest red possible throughout with no trace of black. Heat the third piece a trifle hotter, and continue to heat each piece hotter than the preceding one until they are all hardened, heating number 6 to what is familiarly termed a *white* heat.

Previous to heating, each piece should be stamped in two places, as shown in Fig. 21, in order that the pieces may be broken across the center, as indicated by the dotted lines, and yet the halves of the same piece be easily recognized. When heating, commence with the piece marked 1, and heat consecutively. After hardening them all at the different heats, dry thoroughly in saw dust or by any means whereby the surface may be made perfectly dry, after which they may be broken. This can be done by screwing the piece in the jaws of a vise, putting about one half of it below the tops of the jaws. With a hammer the upper part may be broken off, being careful that the piece does not fly and strike so as to stain the walls of the fracture; or the part projecting above the vise may be caught between the jaws of a monkey wrench and the piece broken.

An examination of the piece marked Fig. 22 will show it to be somewhat hardened. The grain will not be especially fine and will have a peculiar appearance. No. 2 will be very hard and the grain will be very fine. It will break with very ragged walls, as shown. No. 3 will also be very hard and the grain not as fine as No. 2. The grain of No. 4 will be coarser than No. 3. No. 5 will be coarser than No. 4, while the grain of No. 6 will be extremely coarse and the steel unfitted for anything but the scrap heap.

It will pay any man who is desirous of learning to



1 2 3 4 5 6

Fig. 22. Test Pieces of Steel broken to show grain due to different heats.

harden steel *properly* to try this experiment. The steel will cost him but a few cents, and it need take but a short time to heat it; but the knowledge gained of the action of heat on tool steel will be of inestimable value to him, as he can readily see the effects of proper and improper heating on the structure and strength of steel.

If the operator notes carefully the heats, he will be surprised at the difference in the amount of force necessary to break a piece of steel hardened at the refining heat and one heated slightly above this temperature, which, in fact, is hardly discernible to the eye in the light of an ordinary blacksmith's shop. The difference in the strength of a piece hardened at the refining heat and one heated to a *full red* is especially noticeable. In the former case it seems almost impossible to break it by a blow of a hammer, and it seldom can be broken across the center, so great is the adhesion between the molecules that make up the piece of steel, while in the case of a piece heated to a full red, the piece may be broken easily, as compared with the other. When one takes into consideration the fact that the ordinary workman heats steel when hardening to a full red oftener than to the refining heat, it is wonderful that the results obtained are as satisfactory as they are.

As stated, the temperature to which a piece of steel must be heated in order to refine it, depends on the composition of the steel. Tests of different steels have led authorities on this subject to the conclusion that it is necessary to heat a piece of steel to a temperature between 800° and 1200° Fahr. in order that it may harden when plunged in a cooling bath. Jarolineck places the temperature at 932° F. (500° C.) as

determined by experiments made by him, while other authorities claim best results when the steel was heated to 1200° F. (about 650° C). As this difference (268° F.) involves a wide range of heat, it is evident that steels containing different percentages of carbon were used in the various tests.

If a piece of steel be heated to the refining heat and then quenched as soon as the heat is uniform throughout the piece, the steel is in the best condition possible for most uses. It should be quenched as soon as it is uniformly heated to the proper temperature. If subjected to heat after it reaches this temperature, it will become somewhat hotter. In fact, it has been ascertained by experiment that after steel is heated to a low red the temperature may be raised, and the difference in the heat not be discernible to the eye. For this reason it is advisable, if *best* results are desired, to quench *as soon as the desired uniform heat is attained.*

It is also important that steel should be heated uniformly. If a square block be heated so that the center is of the proper heat and the ends and corners are hotter, strains are set up in the piece, and it is very liable to crack when hardened. This also applies to a piece of any shape. While it is extremely necessary that the operator observe the greatest possible care in regard to the quantity of heat given steel, yet it does not harm steel as much to heat it a trifle too hot as it does to heat it unevenly, for while the higher heat unfits it for doing the maximum amount of work possible, the uneven heat is very liable to cause it to crack when hardened.

A piece of steel should not be heated faster than is possible to maintain a uniform heat. By this is meant

the heating should not be forced so that the outside is red hot while the center is black because in all probability the furnace would be so hot that the outside of the article would keep growing hotter while the center was getting to the desired heat. The result would be an uneven heat. Neither should a piece of steel be any *longer* in heating than is necessary, because after it is red hot, it will, if exposed to the action of the air, become somewhat decarbonized on the surface, thus materially affecting the steel. Tool steel should be heated as fast as it will take heat, and no faster. A piece should not be forced by heating the furnace to a temperature that will affect the surface while the heat is equalizing. Steel should never be heated too hot, and allowed to cool to what is considered the proper heat, and then hardened, as the grain will be as coarse as if dipped at the high heat.

The grain of steel remains in the condition the highest heat received leaves it, until it is reheated, when it is adjusted to that heat. The condition of the grain of the steel is an unvarying guide as to the amount of heat it received the last time it was heated. For instance, a piece of steel is heated to the temperature of the piece marked 4 Fig. 22 in our experiment. Now, take one of the broken pieces and reheat it to a temperature given the piece marked 2, which was the refining heat. Break this piece. An examination will reveal the fact that the grain has the same structure as the piece marked 2, thus proving that the grain of steel conforms to the last heat given it. This does not necessarily prove that a piece of steel is capable of doing the amount of work after it has been heated hotter than it should have been, and then reheated to a

lower heat, thus closing the pores; but it is better than if in the condition the high heat would leave it.

Steel should always be hardened on what is known as a "rising" heat, never on a "falling" heat, is the advice an old hardener gave the writer when a boy, learning his trade, and he has found it true. It also agrees with the advice of most writers on this subject. It is quite necessary, in order to get uniform results, to move the articles around in the furnace and turn them over occasionally. When round (cylindrical) pieces of steel, having no teeth, projections, or other irregularities on its surface, are being heated for hardening, it is necessary to turn them occasionally, as, if left in one position without turning, until it is red hot, no matter how uniform the heat may be, it will, in all probability, have a soft line the entire length of the top side as it lay in the fire. It will also be found by experiment that round pieces are more liable to crack from uneven heating than pieces of almost any other shape; neither will they safely stand as high a degree of heat as some pieces, on account of their shape, which makes them offer greater resistance to a change of form.

If possible, when heating articles having heavy and light sections adjoining each other, as shown in Fig. 23, heat the heavy portion first, then the lighter one; but if this is not possible, have a slow fire, in order that the light part may not be overheated before the heavy one is to the required heat. The muffle furnace furnishes a very satisfactory method of heating steel, because the products of combustion cannot come in contact with the steel, and oxidation from the action of the air is done away with or reduced to the minimum. If it is not possible to use a furnace of this description,

very good results may be obtained by enclosing the article in a piece of pipe or tube and heating in an open fire, because in this case the steel is not exposed to the action of the fire. It is necessary to turn the work over occasionally in order to get a uniform heat.

It is never advisable to use any kind of fire where the air from the blast can strike the piece being heated, or it will crack in innumerable places. The steel will look as though it were full of hairs. For this reason, if obliged to use a blacksmith's forge, build a fire high enough to do away with any tendency of this trouble. A fire of old coals *should not* be used if the article to be heated is of any size, as the goodness is burned out of the coal, and it will be found necessary to use a strong blast in order to have a fire hot enough to heat the piece. As a consequence, the air strikes the piece with the result mentioned.

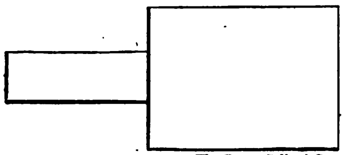


Figure 23. A piece for a slow fire.

Steel should not be heated in a manner that leaves one side exposed to the air, or the exposed side will become oxidized to a considerable extent, and as the piece is turned in the fire the whole surface becomes oxidized and resembles a piece of burnt steel. The surface is not of any use, as the carbon is burned out, and it cannot be hardened. Some makes of steel give off their surface carbon very readily if exposed to the air when red hot. If a tool made from one of these steels be heated in a manner that allows the air to come in contact with it, the outside becomes decarbonized.

and consequently is soft, while the metal underneath the surface is extremely hard. Now, this might not be harmful in the case of a tool whose outer surface was to be ground away, but if the surface of a tap, formed mill or similar tool becomes decarbonized, it is practically useless. Now, if these same tools had been heated in a muffle furnace or in a piece of pipe in the open fire, removed from the action of the fire and the air, the result would have been that the tool would have given excellent satisfaction. While all makes of steel are not so sensitive to the action of the fire and air when they are red hot, yet any steel gives better results if it is removed from their action while in this condition.

A man experienced in the effects of heat on steel is surprised at the apparent indifference of some hardeners when heating steel. A tool hardened properly and tested for strength in a testing machine will be found very much stronger than if heated a trifle hotter. When we consider that hardness, toughness and closeness of grain are the qualities desired in a cutting tool, we realize that there is nothing gained by heating tool steel above the refining heat for most work. Steel quenched at this heat is very hard, tough, and the grain is the finest possible. Now, every degree of heat which it receives above this point unfits it for doing the maximum amount of work possible, because it causes the steel to be brittle and makes the grain coarse.

The writer has made exhaustive experiments in regard to the effects of heat on the strength of steel, and assures the reader that a piece of steel hardened at the refining heat requires a much greater force to break it than one heated to a full red. Knowing this,

the reader can judge how much heavier cuts can be taken with a tool properly heated than with one heated too hot, as the steel is made brittle, and in this condition is more liable to chip or flake off under pressure. The grain being coarse does not present a dense body, but the internal structure has a honeycomb appearance; consequently when pressure is applied the surface caves in, because it does not have the backing it would if the grain were compact.

Reheating to Remove Strains.

As steel heated red-hot and cooled quickly contracts, and as the outer surface hardens and becomes rigid before the interior of the piece has ceased contracting and altering its form and the position of its molecules, the molecules that make up the interior of the piece cannot assume the exact positions they should; consequently, strains are set up. Now, if the outer portion of the article is sufficiently strong to resist the tendency of the interior of the piece to alter its form, it may not crack or it may resist the strain for a considerable length of time. But for some cause a certain portion of the exterior of the piece becomes weakened, or the conditions are such that the outside can not longer resist the internal strain, and the piece is cracked, or it may burst. Many times large, heavy pieces of steel will burst with a report as loud as a gun, and pieces of the steel will be carried for some distance by the force exerted.

Now, in order to avoid this tendency, it is neces-

sary to reheat the piece as soon as it is taken from the hardening bath, to a temperature that allows the various portions of the piece to conform to one another. A piece of hardened steel becomes pliable to a degree when heated, the amount of pliability depending on the temperature to which the piece is heated. This is illustrated elsewhere in the case of articles crooked in hardening, which are straightened after heating to a certain temperature. After cooling they remain the shape given, but were we to attempt to spring them as much when cold, they would certainly break.

It is advisable, after taking a piece of hardened steel from the bath, to hold it over a fire or in some manner subject it to heat, in order that it may become pliable enough to remove the tendency to crack from internal strains.

The method pursued in removing the strains varies. If an open fire is at hand, the piece may be held over this until heated to the proper temperature. It should be constantly turned, in order to insure uniform results. When pieces are hardened in large quantities, this is a very expensive practice. In such cases, it is advisable to have a tank of oil, which is kept at the desired temperature, this being gauged by means of a thermometer.

A very satisfactory method, and one used by the writer for many years, consists in using a tank of water, the contents of which are kept at the boiling point (212°). When a piece of hardened steel is removed from the bath, it is immediately dropped in the boiling water. The tank has a catch pan to receive the work, as shown in Fig. 24. A steam pipe is connected with the tank in order to keep the water at the

desired temperature. It is, of course, necessary to provide an overflow pipe, as represented.

When it is not considered advisable to procure a tank, as represented, a kettle of water may be placed over a fire and brought to the boiling point and used as described.

When it is thought to be advisable to remove the tendency to crack from internal strains and draw the temper at the same time, it may be done by heating a kettle of oil to the desired temperature, gauging the heat by a thermometer. The pieces, as they are taken from the hardening bath, may be dropped in this and left long enough to insure uniform heating.

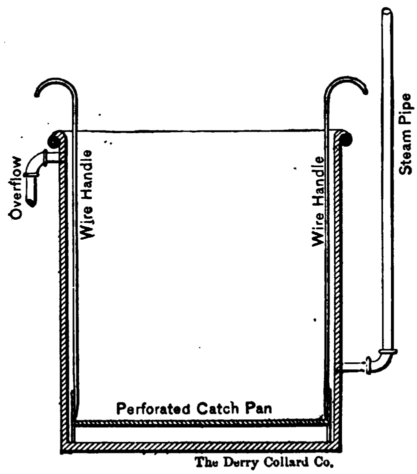


Figure 24. Tank of boiling water for removing internal strains.

Should it be considered advisable to heat articles of irregular shape, having heavy and light portions adjoining each other, it would not be advisable to suddenly immerse them in liquid heated to 300°, 400° or 500° Fahr., as the unequal expansion might cause the pieces to crack where the heavy and light portions joined. In such cases it is sometimes considered advisable to place them in a kettle of boiling water first, removing

them from time to time and placing in the kettle of oil, heated to the temperature to which the pieces must be heated in drawing temper; or two kettles of oil, heated to different temperatures, are sometimes used, the first being kept at 250° or as as near that as possible, the other being the desired temperature. When the pieces are removed from the first kettle and placed in the second, it, of course, reduces the temperature of the oil, but it gradually rises to the desired point when the articles are removed.

Forging.

It is not the writer's intention to devote much space to explanation of the method in which steel should be forged for the various cutting tools. In order to do the subject justice, it would be necessary to devote more space than can be spared, but the forging and hardening of a tool are so closely identified, it seems necessary to briefly consider the subject.

Many tools are rendered unfit for use by the treatment they receive in the forge shop, and as it is the custom in many shops to have the forging done by one man, and the hardening by another, a great amount of trouble is experienced, because each tries to lay any trouble that comes from the hardened product to the other.

Heating is the most important of the operations to which it is necessary to subject steel, whether it be for forging, annealing or hardening.

Superiority of hammered steel.

Unless steel is uniformly heated throughout, violent strains are set up; when the piece is hardened these manifest themselves. If the steel is not heated uniformly throughout the mass, it cannot flow evenly under the blows of the hammer, consequently the grain is not closed in a uniform manner.

While it is necessary, in order to get satisfactory results, to heat steel hot enough to make it plastic, in order that it may be hammered to shape, care should be exercised that it is not overheated, or the grain will be opened to an extent that it can not be closed by any means at hand in the ordinary forge shop.

If a large piece of steel requiring considerable change in size is to be forged, and means are at hand to forge it with heavy blows, it can safely be given a higher heat than a smaller article which does not require much change of size or form.

If tool steel is hammered carefully, with heavy blows while it is the hottest, and then with lighter, more rapid blows as it cools, the grain will be closed and become very fine.

When the temperature is reduced to a low red, care should be exercised, for when traces of black begin to show through the red, it is dangerous to then give it any heavy blows, as they would crush the grain.

By actual test it has been proven time and again that steel, which has been properly hammered, is superior to the same steel as it comes from the steel mill, but unless the work is done by an intelligent smith, who understands the effect of heat on the structure of steel, the forging will have the opposite effect to the one desired.

Many steel manufacturers advocate the purchase

of steel in bars of the desired size, and do not advise forging, claiming best results if the article is machined to size and shape. The reason for this is, that there are many careless, ignorant workers of steel in the various blacksmith shops—men who either do not know the effects of improper methods of heating and hammering, or knowing, do not care. As a consequence, a great quantity of steel is annually rendered unfit for doing the work it might do were it treated properly.

For this reason it is advisable to machine a piece of steel to shape, rather than to have it forged by any but a skillful smith. Yet the fact remains that a piece of steel heated and hammered properly will do more work than a tool of the same description cut from the same bar and machined to shape, even if it is hardened in exactly the same manner.

A piece of steel properly forged is known by tool makers as "hammer refined" steel, and is highly valued by them for tools which are expected to do extra hard work. Tool steel is furnished in bars, blanks or forgings of almost any desired shape.

The smith should bear in mind that heats which are too high open the grain, thereby weakening the steel and making it incapable of doing the largest amount of work possible. If steel is hammered when too cold, the grain is crushed, causing it to crack when hardened; or if it does not crack, the cutting edges will flake off when in use. If the steel is unevenly heated, that is, the outside heated hotter than the inside, the outside portion being softer will respond to the action of the hammer more readily than the less plastic interior, and the outer portion will be torn apart.

Too often it happens that when the smith is rushed

with work he will attempt to heat a large bar of iron for forging, and while that is heating, will try to forge or harden tools someone is waiting for. The spirit of willingness to accommodate is commendable, but a decided lack of judgment is noticeable, because a fire suitable for heating a piece of iron to a forging heat is in no ways adapted to heating a tool either for forging or hardening.

Then again, if the smith is heating iron to its proper forging heat, his eyes are in no condition to properly discern the correct heat to give a piece of *tool steel.*

Annealing.

According to the generally accepted definition of the term, the object of annealing steel is to soften it in order that it may be machined at the minimum cost of labor and tools.

The method pursued in annealing steel depends, as a rule, on the facilities which the shop possesses for doing this class of work. A piece may be softened somewhat by heating red-hot and laying it to one side to cool in the air, provided it is not placed on any substance that will chill it. Neither should it be placed where any current of air can strike it, or it will cool too quickly to become soft. In fact, it would very likely be harder than if worked without attempting to anneal it.

The young hardener should understand that a

piece of steel is hardened by heating red-hot and cooling quickly; the more rapid the process of cooling, the harder the steel will be. Annealing has the opposite effect. Steel is annealed by heating red-hot and cooling slowly; the greater the amount of time consumed in the cooling operation, the softer the steel will be, everything else being equal. Now, it is evident that, if a piece of steel be heated to a red and placed on an anvil or other piece of cold metal or thrown on the floor, the portion laying on the cold substance will chill and the process of hardening, rather than annealing, will be carried on.

The same is true if a piece is placed where a current of air can strike it, even if it is warm air, as it will be cooler than the steel and the heat in the steel will be taken up by the air. Thus, the operation will be the opposite of the one desired.

It is the custom in many shops to anneal steel by heating and putting it in a box of ashes or lime. Now, this may be advisable, or it may not be, according to the condition of the contents of the annealing box. If the room in which the box is kept is damp, the ashes or lime, especially the lime, will absorb enough moisture to chill the piece of red-hot steel, particularly if it be small or thin. So we have again a piece of steel hardened to a degree, instead of annealed. When steel is to be annealed by this process, it is advisable to heat a piece of iron or scrap steel and bury it in the ashes or lime, leaving it there until the piece to be annealed is properly heated, when it may be removed, and the piece to be annealed put in its place. The ashes or lime being heated, and every trace of moisture removed, the process of cooling will be slow and the results

satisfactory. A box of lime furnishes an excellent method of annealing steel, if the precaution mentioned is observed.

A very satisfactory method of annealing, which has been used by the writer many times where there was only one or two pieces to anneal at a time, consists in taking an iron box, putting two or three inches of ashes in the bottom and laying a piece of board a trifle larger than the work on them. Heat the pieces to be annealed to the proper degree, lay them on the board, lay another piece of board on top of them, and fill the box with ashes, as shown in Fig. 25. The pieces of board will smoulder and keep the steel hot for a long time. The process of cooling will be very slow.

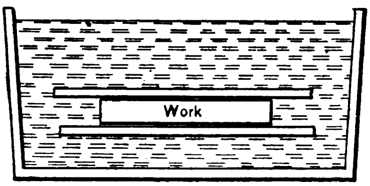


Figure 25.

An iron box filled with ashes for annealing between boards.

There is a method of annealing practiced in some shops which, while it has many advocates, cannot be recommended by the writer, except as a means of annealing a piece of steel that is wanted right away. It is known as cold water annealing. This method has advocates among old hardeners, some of whom get excellent results; but as a method of annealing to be practiced by one who is not thoroughly familiar with the action of fire and water on tool steel, its use is hardly to be advocated. The steel is heated to a red

and allowed to cool in the air where no current of air can strike it, held in a dark place, and when every trace of red has disappeared, plunged in water and left until cold. The steel will be softer if plunged into soapy water or oil.

This answers in an emergency, but on account of the ends cooling faster than the center and the smaller portions cooling more rapidly than the larger ones, it is apparent that the piece of steel must be of an uneven temperature throughout when cooled.

The method practiced in many shops of heating a piece of steel in a furnace to the proper annealing heat, using gas, oil or gasoline as fuel, then shutting off the supply and allowing the work to cool down with the furnace, is attended with varying results. While many mechanics advocate this method and claim excellent results, and it has been used by the writer to his entire satisfaction, yet several cases have come to his notice of late where parties had annealed this way with results that were far from satisfactory. Investigation showed that in heating the steel the furnace had been forced in order to heat the piece quickly, and as the steel was heated by radiation it was necessary that the walls of the furnace should be hotter than the piece of steel being heated.

When the steel had apparently reached the proper heat, the supply of fuel was shut off, but the inside walls of the furnace, being much hotter than the work, imparted heat to the steel after the fire was put out, with the result that the steel was overheated and injured, and in some cases entirely unfitted for the use it was intended for. A steel maker of national reputation says that "many thousand dollars' worth of steel are

ruined annually in this way, and it is in every way about the worst method of annealing that was ever devised."

Knowing the vast amount of trouble caused by attempts of various parties to use this method, the writer feels it his duty to condemn a method he has used successfully under favorable circumstances, because all mechanics are not so favorably situated. They do not use the same care in heating steel, especially when it is nearly to the proper temperature, but insist on forcing it, not only to the detriment of the edges and corners, which are bound to heat faster than the center. In this way the whole piece is ruined or injured, because the furnace is hotter than the steel, and when the fire was extinguished, the furnace was closed and there was no means of looking in to determine the amount of heat the steel was receiving, but the results showed it had been heated too much for its good.

Now, if a comparatively small furnace is used, or one having light walls, which will not hold the heat for a very great length of time, the danger of over-heating by radiation after the fire is extinguished is reduced to the minimum. But on the contrary, if the furnace has heavy walls of masonry, capable of retaining the excessive heat for a considerable length of time, the liability of overheating is very great.

A method of annealing that gives universal satisfaction when properly done, and is used in many shops, consists in packing the steel in iron boxes and filling the spaces between the pieces of steel with powdered charcoal. It is necessary when annealing by this method to place one or two inches of charcoal in the bottom of the box before putting in any steel. Do not

allow the pieces of steel to come within one-half inch of each other in the box, or within one inch of the box at any point.

When nearly full, fill the balance of the space with charcoal, put on the cover and seal the edges with fire-clay. The reason for keeping the steel from coming into contact with the box is that the iron, especially

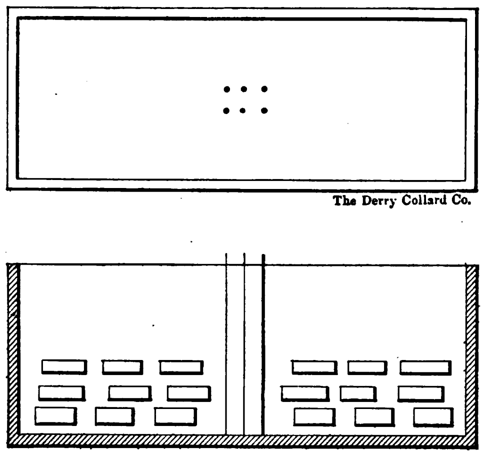


Figure 26. Iron box for annealing.

cast iron, has a great affinity for carbon, and will, when they are both red hot, extract it from the steel, leaving the latter somewhat decarbonized at the point of contact.

In order to be able to determine when the contents of the box are heated to the proper degree, several ¼ inch holes should be drilled through the center of the cover and a $\frac{3}{16}$ wire run down through each of these

to the bottom of the box, as shown in the sectional view, Fig. 26.

When the box has been in the fire long enough, according to the judgment of the operator, to heat through, draw one of these wires by means of a pair of long-handled tongs, or by a pair of ordinary length, slipping a piece of gas pipe on each leg to give the required length. If the wire drawn shows hot the entire length, the operator may rest assured that the steel is of the same temperature, because the wire was run down between the pieces at the center of the box. If the wire did not show red-hot, wait a while and draw another. When a wire is drawn that shows the proper degree of heat, the box should be left long enough to insure its being heated uniformily throughout, then the fire may be extinguished. If the walls of the furnace are much hotter than the boxes, the door may be left open until they are somewhat cool. If the furnace shows a disposition to heat the boxes too hot with the door open, they may be removed for a few minutes until the furnace is somewhat cooler, when the boxes may be returned to the furnace, the door closed and the work allowed to cool slowly.

A method that insures excellent results is to plan, if possible, to empty one furnace of work to be hardened some little time before the work being annealed is sufficiently heated. Keep the first furnace closed to retain the heat as much as possible, so that it will pass the stage where it is liable to overheat the articles, and it will commence to cool down somewhat. When the work being heated for annealing has been subjected to the heat a sufficient length of time, the boxes may be removed from the furnace they were heated in and

placed in the first furnace. All danger of heating too hot from radiation is done away with. This method cannot, of course, be practiced if there is but one furnace.

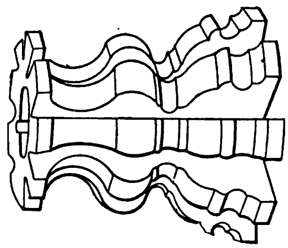


Figure 27. An irregular milling cutter.

While it is generally understood that the object of annealing steel is to make it soft enough to work to advantage, yet from the hardener's standpoint annealing has another and more important office than simply to make steel workable.

A piece of steel as it comes from the steel mill or forge shop is very apt to show a difference of grain in various parts of the piece, due to uneven heating and an unequal closing of the pores in the process of rolling or hammering; consequently there exists in the piece internal strains. In order to overcome the effect of these internal strains, which must manifest themselves when the steel is hardened, the work should be blocked out somewhere near the shape and annealed. If the piece is a milling machine cutter, punch press die, or similar tool, having one or more holes through it, the holes should be made somewhat smaller than finish size before annealing to remove strains. If it is a milling machine cutter of irregular contour, as

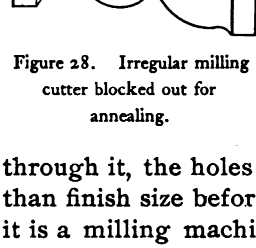


Figure 28. Irregular milling cutter blocked out for annealing.

shown in Fig. 27, it should be blocked out as represented in Fig. 28. The benefit gained in pursuing this course is that it is heated for annealing under as nearly as possible the same conditions, so far as shape is concerned, as when heated for hardening; consequently the tendency to change shape will be overcome in the annealing.

Long pieces of steel that are to be hardened will give much better results if roughed out—that is, all scale and outside surface removed by planing or turning—then thoroughly annealed. Should the piece spring when annealing do not straighten when cold, as it is almost sure to spring when hardened. If it is not sufficiently large to turn out without straightening, it should be heated red-hot and straightened. The hardener is blamed many times because a costly reamer or broach or similar tool is crooked in hardening, when in reality the blame rests with the man who turned or planed it to size.

After it was annealed he tested it in the lathe, and finding it running out somewhat he takes it to an iron block or an anvil, and commences to hammer. He finally gets it fairly straight, and feels quite proud of his job. He doesn't like to see a man machine a piece of steel that is crooked even if it will finish out, when a few strokes of a hammer will fix it all right.

He has, by means of hammering, set up a system of internal strains much more serious than the ones removed by the process of annealing. He commences to machine the piece. Every time he goes below the effects of a hammer mark, the particles of the piece of steel "goes" or moves in some direction at this point, and it is necessary to repeat the operation of hammer

persuasion again, with the effect that by the time the article is ready to harden, it is in no condition to be hardened. It is either crooked in all directions, or it is only waiting for the fire to relieve it and allow it to go where it will. When the hardener gets through with it, it looks like a cow's horn, and of course the hardener is blamed.

If he happens to be a man without any machine shop experience, or does not understand the nature and peculiarities of steel, he does not know where to place the blame, and perhaps it wouldn't do any good if he did.

He, of course, isn't going to shoulder it, so the fault is laid to the steel, and, in consequence, if the trouble continues, another make of steel is bought because the man in charge does not know or cannot spend time to locate the trouble. It cannot be the fault of the man in the shop, they say; it must be the steel; or they decide it must be the hardener, because some other concern with whom they are acquainted use this same steel and have no trouble, so the hardener has to stand the blame.

A successful business man is quoted as saying: "If I were to drive a mule team, I would study the nature of mules." A man to be a successful hardener must study the nature of steel. He must know what steel is liable to do under certain conditions, and how to avoid undesirable results. No matter whether it relates to his department or some other department, he should know that it is possible for the tool maker to treat the steel in such a manner that results anything but satisfactory *must* follow when it is hardened. He should also understand that he may make the steel un-

fit for use by overheating when annealing, or he may not heat it uniformly throughout, and consequently does not remove the tendency to spring from internal strains. If a satisfactory steel is furnished, the hardener should never blame the steel for bad results which are caused by his ignorance or carelessness, because he may be furnished with an undesirable steel next time. And in time those over him in authority will tire of complaints about a steel that another concern is satisfied with.

A method of annealing steel which the writer has seen practiced in some shops, but which should never be used when annealing tool steel, is to pack the articles in a box with cast iron dust or chips. Now this method works nicely when annealing forgings or other pieces of *machinery* steel which were hard and show glassy spots and cannot be softened by the ordinary processes of annealing. The cast iron seems to have an affinity for the impurities liable to be present in the low grade steels, and the result is very soft and easily worked pieces. But if the method is applied to tool steel the carbon is extracted to an extent which is highly injurious to it. To be sure, tool steel can be annealed very *soft* if packed as described, but the result is anything but desirable.

The writer had charge at one time of a hardening plant where, among other things, many hundred pairs of bicycle cranks were hardened every week. A lot of ten thousand crank forgings were received and started through the regular routine necessary to get them in a condition for hardening. When the first batch reached the hardener it was found impossible to harden them by ordinary processes. And, by the way,

samples had been forged and sent us ahead of the main batch which had been tested and found all right. They hardened and tempered in a satisfactory manner and stood the required tests.

The first test was made by placing each end of the crank on the two projections of an iron block, as shown in Fig. 29, and struck in the center a blow with a heavy hammer in the hands of an experienced inspector. They were then taken to a testing machine and given a very severe test, which consisted in holding the end which went on the axle in a fixed position. Pressure was applied to the other end until the crank was bent a certain amount. The pressure was removed and the crank was supposed to come back straight, but the cranks in the large batch would not harden.

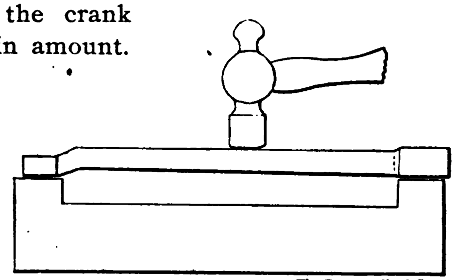


Figure 29. Testing a bicycle crank.

Investigation at the forge shop where we procured them, showed that through some mistake the cranks, after being forged, were packed in cast iron dust or chips in the annealing pot. Orders had been given to anneal some machine steel forgings in this manner and to anneal the cranks in charcoal, but someone got the orders mixed, and hence the trouble. The cranks were made of 40-point carbon open hearth steel. We remedied the defect by packing them in iron boxes with

wood charcoal, and submitting them to heat in the furnace for several hours after they were red-hot. In this way we got them in condition to harden.

Another method which works nicely when applied to annealing machinery steel, but which is entirely unfitted for tool steel, is to pack the pieces in annealing boxes in expended bone—i. e., bone that has been previously used in case hardening. As before stated, machinery steel packed in this manner, and heated, gives excellent results. It is also an excellent way of annealing cast iron (by this is meant small castings, as typewriter parts, etc., which must be very soft in order to machine nicely).

But tool steel should never be packed in any form of bone, as bone contains phosphorus, and this is the most injurious of any of the impurities which tool steel contains. The steel maker uses every effort possible to reduce the percentage of this impurity to the lowest possible point, for while it is a hardening agent, its presence makes tool steel brittle, so that it is folly to pay a good price for steel on which the manufacturer has spent much time and money to rid of undesirable impurities and consequently must charge a high price for, and then use some method whereby the steel is charged with these very impurities.

In concluding, it may not be amiss to emphasize a few facts that have already been mentioned. Do not overheat steel when annealing or it will be permanently injured. Do not subject it to heat for a longer period of time after it becomes uniformly heated throughout than is necessary to accomplish the desired result. For while it is necessary to heat the steel when annealing to as high a heat as will be needed in harden-

ing, and while the steel must be subjected for a period of time to heat that insures its being of the same temperature in the middle of the piece as it is at the surface, yet we must be careful not to overdo it.

Steel kept at a red heat for a long period of time, even if it is not overheated, will betray the fact when the temper is drawn after hardening, if it does not at any other time. A piece of steel which is kept hot for too long a period when annealing, may apparently harden all right, but when the temper is drawn the hardness apparently runs out—i. e., when the piece is heated to a straw color it may be filed very readily, whereas a piece from the same bar not annealed, or which was *properly* annealed and then hardened and drawn to the same temper color, would show all right —i. e., a file would just catch it.

Uniform temperature when heating for annealing is as desirable as when heating for hardening. If a large block is unevenly heated, its corners and edges are hotter than the main part of the block. Violent strains are set up at these points, so it will be readily apparent that uniform heating during the various processes is one of the secrets of successful hardening of tool steel.

There are other methods of annealing steel, methods whereby the surface does not become oxidized by the process of heating, as when heating drill rods, etc., but as these methods are not likely to be used by mechanics in every day shops, their consideration would be entirely out of place at this time.

Lastly, remember that any process of annealing that takes from the steel any of its hardening properties should never be used, no matter how soft it will

make the steel. It is better to work a piece of steel which is hard, than to unfit it for doing its maximum amount of duty when finished; but *it is* possible to anneal most steel so that it will be workable and yet harden in a satisfactory manner; in fact, in a much more satisfactory manner than if not annealed.

When annealing high carbon steel, and it is desirable to retain the full amount of carbon in the steel, it is advisable to pack in the annealing box with charred leather, instead of wood charcoal.

When it is desirable to harden the surface of low carbon steel harder than it would naturally be, it may be machined nearly to size, packed in a box with charred leather and run for a length of time sufficient to give the desired results. After machining to shape, it may be hardened in the ordinary manner.

Hardening Baths.

When steel is heated to the proper hardening heat it is plunged into some cooling bath to harden. The rapidity with which the heat is absorbed by the bath determines the hardness of the steel. Knowing this, it is possible by the use of baths of various kinds to give steel the different degrees of hardness and toughness. A bath that will absorb the heat contained in a piece of steel the quickest, will make it the hardest, everything else being equal. A bath of mercury will cause a piece of steel plunged in it to be harder than if it were plunged in any of the liquids commonly used

for this purpose, but as such a bath would be extremely expensive, it is but little used. Clear cold water is the one more commonly used than any other, and for most cutting and similar tools gives good satisfaction, although many old hardeners claim better success with water that has been boiled, or that has been used for some time, provided it is not dirty or greasy.

A very excellent bath that is used very extensively is made by dissolving all the salt possible in a tank of water, or what is known as a "saturated solution." Salt water, or "brine," as it is commonly called, is used in most shops on certain classes of work, and in some shops it is used altogether where a bath of water is desired.

Different kinds of oil are also used to accomplish various results. When small or thin cutting tools requiring a hard cutting edge are to be hardened, a bath of raw linseed oil, or neat's foot oil, is used.

When toughness is the desired quality, as in hardening a spring, a bath of tallow, sperm oil or lard oil is used. But the nature of steel of different makes varies so much that no one bath answers best for all purposes, or for the same purpose, when applied to steels of different makes. Sometimes it becomes necessary to use a bath containing two or three ingredients in order to accomplish the desired result.

I have in mind a manufacturing concern who made a great many heavy springs. Until they changed the make of steel they had been using for years they had excellent results from hardening in lard oil, but *after* changing they could do nothing with this bath. After considerable experimenting they were advised to use the following mixture: Spermaceti oil 48 parts, neat's

foot oil 45 parts, rendered beef suet 4 parts, resin 3 parts. They had very good results with this bath until a drummer came along with good cigars and a steel two cents a pound cheaper, and then trouble was the result.

By the way, I have visited and known of several shops where a few good cigars or an occasional wine supper, which some glib-tongued salesman was willing to put up for the man who did the buying, caused more trouble than a little in the hardening department. But to return to the hardening of the springs. When the new steel came, the springs would not harden sufficiently in the mixture mentioned. They were finally advised to try a bath of boiling water, and this worked very nicely.

Very small cutting tools, as taps, reamers, counterbores, etc., harden nicely in a bath made by dissolving one pound of citric acid crystals in one gallon of water. This proportion may be used in making a bath of any size.

The following is recommended when it is desired to have the tools hard and tough:

Salt....................	½ teacupful.
Saltpetre..................	½ ounce.
Pulverized alum......	1 teaspoonful.
Soft water................	1 gallon.

The following bath gives excellent results, but care must be exercised in its use, as it is deadly poison. To six quarts of soft water put in one ounce of corrosive sublimate and two handfuls of common table salt. When dissolved it is ready for use.

Sulphuric acid is added to water in various proportions, from one part acid to ten parts water, to

equal parts of acid and water. Some even use clear acid, and although excellent results, so far as the hardened surface is concerned, may be obtained by the use of this acid, steel makers do not advocate its use, claiming that the after-effects are injurious to the steel, that is, it "*rots*" the steel, and the writer's experience substantiates the claims of the steel makers. I do not advocate the use of any of the acids which act directly on steel, provided any other form of bath will give satisfactory results.

There are many other compounds used with success in various shops. Some of these will be mentioned in connection with hardening various tools. As a rule, tool steel that is fit for use for cutting tools will harden in a satisfactory manner in clear water. If the outline is irregular or it is desirable that it should be extra hard, a bath of brine answers admirably. Articles of an irregular shape made of steel liable to crack when hardened should be dipped in water or brine (that is, warmed somewhat), the temperature of the bath depending upon the liability of the piece to crack.

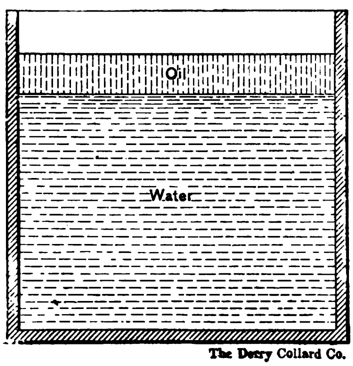


Figure 30. Oil and water bath for hardening.

Tools, as milling cutters, made from high carbon steel, are many times hardened to advantage in a bath

of water having one or two inches of oil on the surface, as shown in Fig. 30. The article is brought to the proper temperature in the fire and immersed in the bath, passing it down through the oil into the water. Enough oil adheres to the red hot steel, especially in the corners of the teeth or projections, to prevent the water acting as suddenly as it otherwise would, thus doing away in a great measure with the tendency to crack.

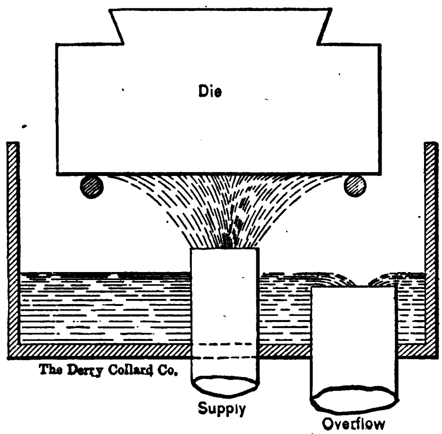


Figure 31. Hardening with jet from bottom.

It is a good plan when hardening large pieces of almost any shape to first dip in water or brine and allow them to remain in this liquid until the surface is hard, then remove and instantly plunge into a tank of oil, allowing them to remain in the oil until cold. This works especially well in the case of such tools as milling machine cutters, punching press dies, etc., where it is not necessary that the hardened surface be very deep.

The depth to which a piece is hardened depends on the length of time it is left in the water. For this purpose old hardeners allow the article to remain in the

water until it ceases to "sing." This is the peculiar noise occasioned by putting a piece of red hot steel in water. When the piece stops singing it is removed from the water and plunged in oil and left until cold.

When pieces are to be hardened, and it is necessary to harden the walls of a hole or some depression, as the face of an impression die, or forming die, or any similar piece, it is necessary if good results are desired, to have a bath which has a stream or jet coming up from the bottom, as shown in Fig. 31. If clear water is used in the bath, the inlet pipe may be connected with some constant supply, but if brine or some solution is used, it becomes necessary to have a supply tank having a pump as shown in Fig. 32. The contents of

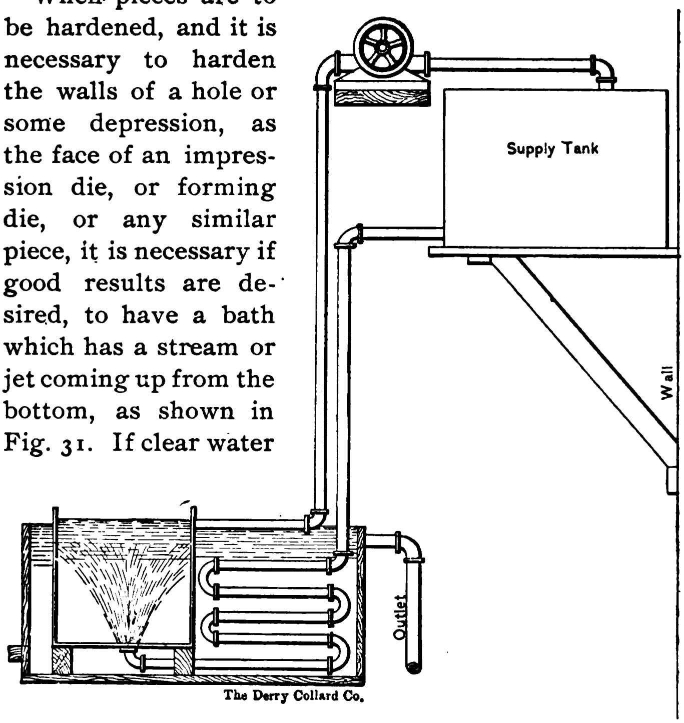


Figure 32. Continuous brine bath.

the bath are pumped into the supply tank and run down the supply pipe as shown.

At times it is desirable to have a tank in which there is no gush or jet of fluid, but where the contents of the bath are kept in motion in order to force the steam away from the surface to be hardened. There are several ways of accomplishing this. Fig. 33 shows a bath having a pipe coming up from the bottom, the jet striking the plate which spreads the fluid. It then comes to the surface through the perforated plate shown.

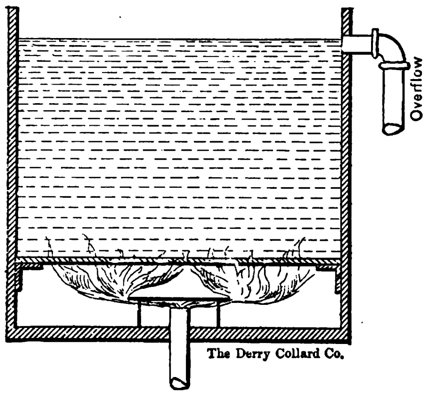


Figure 33. Bath with perforated bottom plate.

Fig. 34 shows a bath in which the contents are kept in motion by some mechanical means contained in the tank. Such a bath may be made by following the suggestions contained

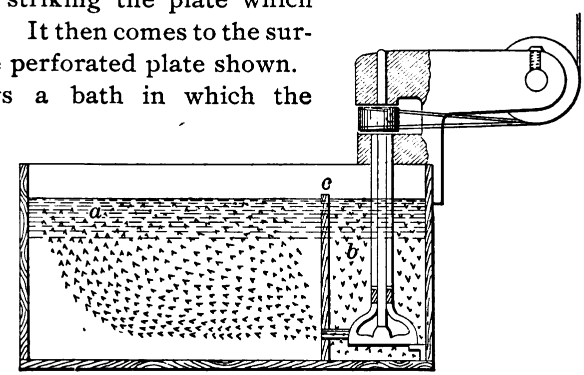


Figure 34. Bath with agitator.

in the illustration. A tank of any convenient size may be made having a partition as shown. The portion of the tank marked *a* is intended to be used for the immersion of the articles being hardened, while *b* contains a pump, Archimedian screw or some similar device for forcing the water into the side *a*.

If a pump is used, the water is forced through the pipe shown. If an Archimedian screw is used, the partition shown should not extend way to the bottom, the water being forced under it. In either case it returns to *b* over the top of the partition *c* as shown, thus insuring a rapid circulation of fluid. This form of bath is especially to be desired where brine or some favorite hardening solution is used. It is also possible to heat the contents of the bath when it is considered advisable, as in the case where articles are to be hardened that are liable to crack in contact with extremely cold liquids. Much more uniform results may be obtained, especially when small, thin pieces are hardened, if a uniform temperature can be maintained in the bath.

In order to keep the contents of the bath at somewhere near a uniform temperature, a small coil of steam pipe may be placed in the tank, and a thermometer may be so placed as to readily show the condition of the bath. While it may seem unnecessary to be so particular about the temperature (and it is unnecessary on most work, as an experienced hardener can determine the temperature very closely by the sense of feeling), yet there are jobs where it is essential that a certain uniform temperature be maintained in order to get uniform results. I do not mean by this that it is practical to attempt to keep the temperature within a few degrees of a given point, but it can be

kept somewhere near in order to get the best results possible.

Sometimes it is necessary to harden the walls of a hole that does not go way through the piece, as a die used for compression work or some forms of dies for striking up cylindrical pieces. Fig. 35 shows a sectional view of a die having a hole part way through it as described. Now, if a piece of work of this description were hardened in a bath where the contents were not agitated, it is doubtful if the walls of the hole would be hardened in the least. The steam generated would blow the liquid out of the hole, and none could enter until the steel was cooled to a point where it could not harden.

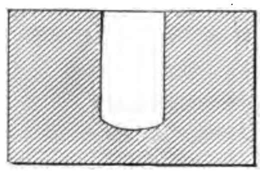


Figure 35. Die with hole.

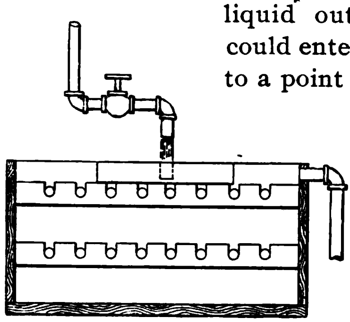


Figure 36. Method of cooling holes in dies.

Better success would follow if it were dipped in a bath having a jet of water coming up from the bottom of the tank, but in this case it would be necessary to invert the piece in order to get the liquid to enter the hole, and if it were dipped in this position, it is probable that enough steam would rise to keep the contents of the bath from affecting the walls near the bottom.

Now, in order to get satisfactory results when hardening work of this character, it will be found best

to have a bath so constructed that the liquid can run into the hole by means of a faucet or pipe, as shown in Fig. 36. If the hole is deep and there is danger of the steam preventing the liquid effectually working at the bottom, a pipe may be run nearly to the bottom, as shown in the sectional view of Fig. 37. The pipe must not be as large as the hole, or the results will not be satisfactory.

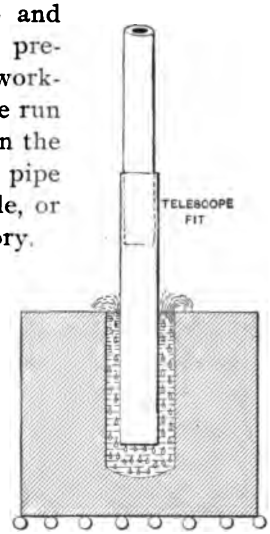


Figure 37. Cooling a deep hole in a die.

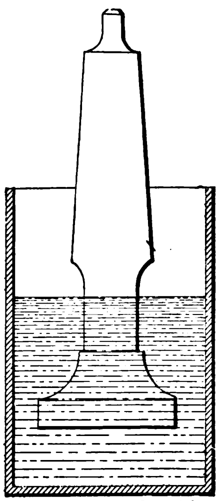


Figure 38. Cooling a shank mill.

Sometimes it is necessary to harden several pieces of a kind whose outline betokens trouble if dipped in a cold bath, and yet it seems necessary to use a cold bath in order to get the desired result. Take, for instance, a shank mill of the shape shown in Fig. 38. If this mill is heated to the proper degree of heat and plunged in a dish containing just enough water or other liquid to harden the teeth before the water gets hot, the teeth

will harden in a satisfactory manner, and the water will heat so as to do away with any danger of cracking the cutter from internal strains. The size of the dish will determine the depth of the hardening. When one piece is hardened the dish may be emptied and filled with cold water for the next.

The writer has seen this scheme used with excellent results, not only on milling cutters, but on broaches, small dies, etc., that showed a tendency to crack when dipped in a large bath of cold fluid. Of course, it should be borne in mind that the dish selected for the bath must be large enough to hold a sufficient amount of liquid to harden the piece the necessary amount before it becomes too hot, but it is also essential that it should not be so large that the contents will not heat, because then there is no difference in its action from that of a large bath.

Generally speaking, however, it is *advisable* to use a *large* bath, having the contents at a temperature of about 60 degrees Fahr., as then the process of contraction, which takes place when the piece is cooling, is uniform.

Delicate articles, however, require a bath having the contents heated somewhat above the temperature mentioned, the temperature depending on the character of the article and the nature of the steel.

It should be borne in mind that a tank or dish of *dirty* water makes a very undesirable bath; neither should one be used having dirt in the bottom, because as the contents are agitated, the dirt rises, preventing the liquid acting in a satisfactory manner.

Baths for Hardening.

The Lead Bath.

When comparatively small pieces of work are to be hardened in large quantities, as, for instance, the various small parts of bicycles, sewing machines and guns, red-hot lead furnishes an excellent means of uniformly heating in a very economical manner. It is a speedy, and at the same time a very reliable means to use, as the heat can be maintained so uniformly, it can be applied safely. By using a proper amount of precaution, there is no danger of burning the outside of the article before the center is heated. Large and small parts are heated alike, and quite a number of pieces can be heated at the same time, thus making it a cheap, rapid, yet reliable way of heating. It is necessary to have a uniform heat under and around the crucible that can be maintained for quite a length of time.

A furnace burning illuminating gas as fuel, gives the most satisfactory results, although excellent results may be obtained by the use of a furnace burning gasoline or crude oil. If it is not found possible to obtain any of these, good results can be obtained by the use of one burning charcoal, hard coal, or coke; but in order to obtain uniform results, a great deal of attention must be paid to the fire.

If but a few pieces are to be hardened at a time,

and it is not considered advisable to purchase or make a furnace especially adapted to this kind of work, a crucible may be placed in a fire on an ordinary blacksmith's forge. Build up around it with bricks, placed far enough away from the crucible to have a fire all around it, and fill this space with charcoal. It will be found necessary to raise the crucible occasionally and poke coals under it.

The most satisfactory crucible is one made of graphite, especially for this purpose. A cast iron one is sometimes used, but as a rule is not as satisfactory and is more costly, as it burns out very quickly.

The graphite crucible should be annealed before using, as this toughens it, reduces the liability of cracking and makes it longer lived. In order to anneal the black lead crucible, place it in any oven or furnace where a uniform heat can be obtained, heat it to a red, take it out and place it where it can cool off slowly without any drafts of air striking it.

It is very essential that the proper quality of lead is used. Red-hot steel is very susceptible to the action of certain impurities. Many brands of lead contain sulphur in such quantities that it is very injurious to the steel. Nothing but chemically pure leads should be used. It is the custom in some shops to use lead of any kind, and when unsatisfactory results are obtained, the method, instead of the material, is condemned, because the operator does not understand the cause of the trouble.

If the lead contains sulphur, even in small quantities, it will ruin the steel. The article will have a honeycomb appearance, and portions of the outside stock will be eaten away. When using lead that is

chemically pure, this difficulty will not be encountered.

Many hardeners are averse to the use of the lead bath in hardening on account of the tendency of the lead to stick to the work. To prevent this trouble, different compounds are used.

The writer has had excellent results with a solution of cyanide of potash in water. Dissolve one pound of powdered cyanide and one gallon of boiling water. Let it cool before using. If this should not prove to prevent the lead sticking, put in a larger portion of cyanide. Some use a strong solution of salt and water. Dip the articles in the solution; place them where they can dry, preferably in a hot place where they will dry more rapidly. It is not safe to put them in the lead when damp, as any moisture would cause the lead to fly.

The writer has used the following mixtures with very gratifying results when hardening such work as small milling cutters, taps, reamers, broaches, cherries, rotary files and similar tools having fine teeth likely to hold the lead. This formula is taken from the report of the Chief of Ordinance of the War Department, and is used in the U. S. Government shops when hardening files. The following is a copy of the report: "Before hardening, the files are treated with a mixture of salt and carbonaceous material to protect the teeth from decarbonization and oxidation. The kinds and proportions of the ingredients are exhibited in the following table:

Pulverized charred leather......	1 lb.
Fine family flour............	1½ lbs.
Fine table salt.................	2 lbs.

The charcoal made from the charred leather should

be titurated until fine enough to pass through a No. 45 sieve. The three ingredients are thoroughly mixed and incorporated while in a dry state, and the water is then added slowly to prevent lumps, until the paste formed has the consistency of ordinary varnish. When ready, the paste is applied to the file with a brush, care being taken to have the teeth well filled with the mixture. The surplus paste is then taken off the file by the brush, and the file is placed on end before a slow fire to dry. If dried too quickly the paste will crack or blister. If not dry enough, the remaining moisture will be transformed into steam when dipped into the hot lead bath, and cause an ebullition or sputtering of the lead, throwing out minute globules of the latter, which may endanger the eyes of the operator. The fusing of the paste upon the surface of the file, indicates the proper heat at which the file should be hardened."

File makers have methods of hardening files that differ very materially from the above process, but it has proved particularly valuable when applied to the tools mentioned. Small articles, if of an even size or thickness throughout, may be put into the lead when they are cold and left until red-hot, although they should be turned over occasionally. But pieces, such as shank mills and similar articles of irregular contour, having large and small parts in connection with each other, should be heated nearly to a red before putting into the lead, as the sudden expansion of the large thin parts would tear them from the more solid portions that could not heat and expand so quickly.

The purpose of putting such pieces into the lead is for the uniform heat that can be finally obtained on the

unequal sizes and thicknesses, making them much less liable to crack when dipped in the bath. If an irregular shaped piece were plunged suddenly into the red-hot lead, and thereby cracked, it probably would not be noticed until it was hardened, and the natural inference would be that it had cracked in the cooling bath; but a careful examination of the fracture would show the walls to be black, proving it to have been subject to heat after it was cracked. If it were sound until dipped in the bath, the walls would have a brighter appearance, although it might be somewhat stained by the contents of the bath, yet they would not be black.

The following question may suggest itself. If the piece of work is to be partly heated in another fire, why not heat to the hardening heat? The reason for this is, that a much more uniform heat can be obtained in the lead crucible than in an ordinary open fire. When it is necessary to harden a portion of the piece, leaving the balance soft, it need only be dipped in the lead the required distance, moving it up and down to prevent a fire-crack. It is likely to crack at the point where the heat leaves off, just as a piece of red-hot steel will crack if dipped into water in such a way that some of the red is out of the bath and the piece held in that position. It then cracks at the point where the contraction ceases, while in the first case it cracks where the expansion ceases.

If impossible to do the first heating in an open fire, or if it is considered advisable to heat it in red-hot lead altogether, the piece may be immersed in the lead, left there for a moment and withdrawn. It may then be immersed again, leaving a little longer than the first time and withdraw it again, repeating the operation

until the steel is heated to a point where the intense heat will not cause it to crack from the sudden change of temperature.

To prevent dross from forming on the lead, keep the surface covered with broken charcoal. This not only has a tendency to prevent dross forming, but the charcoal, catching fire and burning, keeps the surface

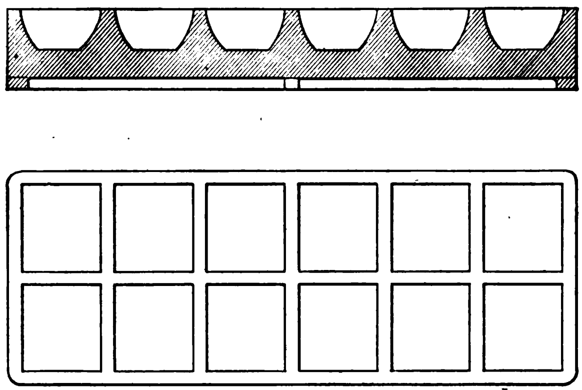


Figure 39. Mould for casting lead.

of the lead at a more uniform heat, than if not used. But despite all these precautions, more or less dross will form in the surface of the lead. This should be skimmed off occasionally, in order that it may not stick to the work.

When no longer using the crucible, the lead should be emptied out, as if left in the crucible until it cools and solidifies, the crucible will probably crack when the lead is heated again. It may be removed by means of a ladle and emptied into small moulds. When the cru-

cible is nearly empty, it may be lifted from the fire and the balance of the lead poured out. As it is necessary to put the lead into the crucible in small pieces, it is best to use a mold of the form shown in Fig. 39, as this makes a very convenient size to put into the crucible again. To get good results when hardening, the lead should be stirred up from the bottom occasionally in order to equalize the heat, as it will be hotter at the bottom than it will be toward the top.

When heating pieces with fine projections or teeth, it is well to use a stiff bristle brush to remove any lead that may stick in the bottom between such projections. This should be done before dipping into the bath, to prevent soft spots. Steel will not harden where lead adheres to it, as the liquid in the bath cannot then come in contact with the steel.

There is no one method of heating steel which is so generally used that is a source of more annoyance than the one under consideration, because attention is not paid to a few simple points. But if a chemically pure lead is used in the crucible, the contents of the crucible is stirred occasionally, and as low a heat as possible is maintained, excellent results will follow.

A serious mistake, which is made many times, is to heat the lead too hot, leaving the piece of work in just long enough to bring the surface to the desired heat, then removing and quenching. The objection to this method is, the heat is not uniform throughout the piece, consequently poor results follow. If the article is left in the lead long enough to become uniformly heated throughout, it will become too hot. If the lead becomes too hot, it is best to plunge a large piece of iron or scrap steel into it, allowing it to absorb the

extra heat, thus reducing it to the proper temperature. It is then safe to go ahead with the heating, and not until then. Do not neglect this precaution.

It will readily be seen that the lead should be of about the same temperature as the steel should be heated, and the articles left in it long enough to become uniformly heated throughout.

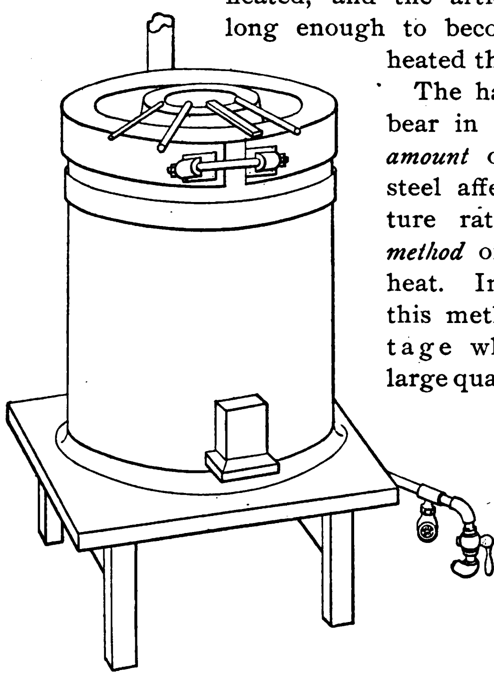


Figure 40. Drying steel before heating.

The hardener should bear in mind that the *amount* of heat given steel affects the structure rather than the *method* of applying the heat. In order to use this method to advantage when hardening large quantities of small articles, quite a number of pieces may be heated at a time in the lead. This may readily be accomplished by dipping a number of pieces in the cyanide solution, laying them on the top of the furnace as shown in Fig. 40. When these are thoroughly dried, place them in the lead, dip another batch in the solution, and lay on the furnace as described. By this time the pieces in the lead will

be hot enough to dip in the bath. As one is taken from the lead, another may be taken from the top of the furnace and put in its place, another should be dipped in the solution and placed on the furnace. In this way a rotation may be kept up, which insures the maximum amount of work in a given time.

Before taking a piece of work from the lead, it should be plunged below the surface and held there long enough to equalize the heat. Articles being heated in lead should be turned over occasionally, in order that they may heat uniformly. If long articles are to be heated by this means, it is necessary to stir the lead from the bottom frequently, or the piece will be the hottest at the end nearest the bottom of the crucible.

When heating certain tools, as long reamers, broaches, etc., it is sometimes advisable to place a piece of cyanide of potassium on the surface of the lead. It will fuse and remain for some time in a body around the steel. The tool may be raised and lowered in the lead through this melted cyanide occasionally, and especially just before quenching in the bath.

If the article is dipped in a bath of water, heated as hot as it is possible to hold the hand in, the teeth will be found very hard and the tendency to spring or crack will be reduced very materially. If it is desirable to have the tool extremely strong, that is, able to stand strains, as would be the case if a broach used for draw-broaching were being hardened, the tool could be heated as described and quenched in a bath of raw linseed oil, or into a bath of sperm oil and tallow, to which is added a small quantity of resin. The amount of resin added should be very small, as it has a ten-

dency to crystallize the steel if too great a proportion is used. Generally speaking, one part resin to 100 parts of oil, or oil and tallow, will be sufficient, and generally it will not be found necessary to use it, if tallow is added to the oil.

Although red-hot lead furnishes an excellent means of heating small articles, and a very satisfactory method of heating certain kinds of tools, yet for most *cutting tools*, the writer has found cyanide of potassium, melted and heated red-hot in a crucible, or a mixture of salt and cyanide of potassium, to give more satisfactory results.

Cyanide of Potassium Bath.

Cyanide of potassium, if placed in a cast iron crucible and heated red-hot, furnishes a method of heating steel that gives very excellent results in many shops.

This method is employed very extensively in heating articles whose shape betokens soft spots when hardened by the ordinary methods. It is also used in hardening dies for transferring impressions onto plates used in printing bank notes and similar work.

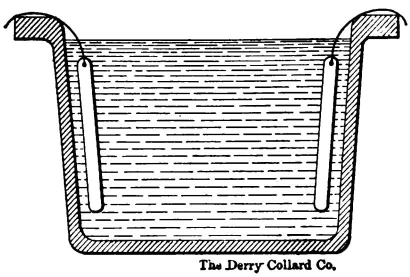


Figure 41. Method of suspending work in cyanide of potassium.

The articles heated by this method are not subject to oxidation from the action of the air on the surface. The cyanide does not have a tendency to stick to the work, and the action

of the cyanide tends to increase the surface hardness, thereby making the tools more durable than when hardened by ordinary methods. Many dies with finely engraved working surfaces are heated by this method and the best of results obtained. In order to get satisfactory results, it is necessary to use *chcmically* pure cyanide of potassium.

It is different from red-hot lead in that iron will not float on its surface, but sinks to the bottom, consequently it is necessary to suspend the pieces being heated with wires which pass over the edge of the crucible in the form of a hook, as shown in Fig. 41.

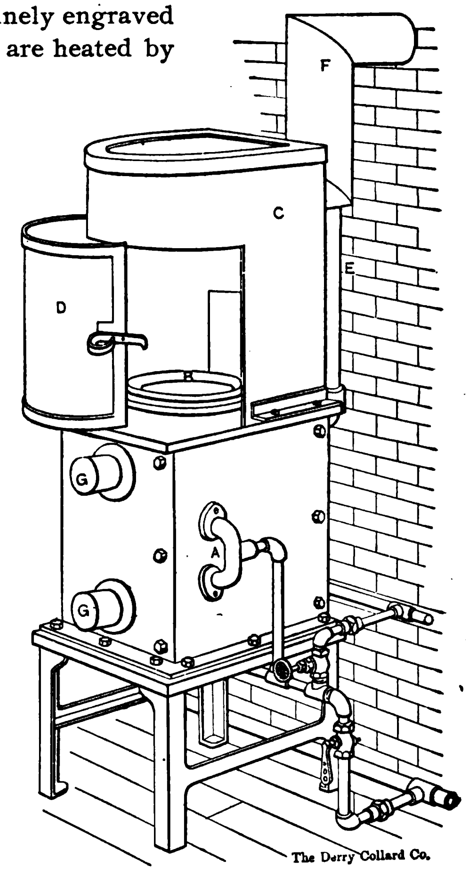


Figure 42. Cyanide hardening furnace, also shown in Figure 18.

About attention to heat.

As cyanide of potassium is a violent poison, the greatest care should be exercised when using it. The fumes of this chemical are very injurious to the workman, consequently a furnace should be used having some means of conveying the fumes into a chimney or ventilating shaft.

A furnace may be procured of the pattern shown in Fig. 42, using illuminating gas as fuel. A is the pipe furnishing fuel to the burners, B the crucible, C the hood, D the door, E the pipe which conducts the products of combustion to the pipe F, the pipe which conveys the fumes and products of combustion into the chimney. The lighting holes are stopped by the fire clay plugs G G.

If it is considered advisable to make a furnace burning hard coal or coke, the same design may be used as illustrated in Fig. 19. For a lead hardening furnace, a hood must be added to prevent the poisonous vapors getting into the room. This hood must be connected with the chimney.

The operator must bear in mind that in order to get satisfactory results, attention must be paid to the amount of heat given the piece of steel, as previously explained. The strength of the hardened piece depends in a greater measure than mechanics generally realize, on the amount of heat given when hardening. In order to get the best results possible, it is necessary to have the steel at the refining heat.

It is easy to be deceived when heating by the method under consideration, as the effect of the cyanide is to cause the surface of steel to harden at a temperature lower than the refining heat. Consequently the portion beneath the surface may not be hardened at all

when the surface shows hard, if tested with a file. It matters not by what method steel is heated for hardening, there is a temperature at which it should be quenched. If not heated to that temperature, it is not as hard as it should be to accomplish the maximum amount of work possible. If heated to a higher temperature, the pores are opened, the steel made brittle and it is unfitted to do the amount of work it should.

Not only is this method valuable because it furnishes a means of heating steel uniformly without danger of its surface becoming oxidized, but if certain points are observed, the most beautiful colors imaginable may be obtained. It is necessary, in order to procure nice colors on the hardened product, that it be nicely polished, and free from dirt and grease. While grease will burn when subjected to a red heat, yet it leaves a stain on the work.

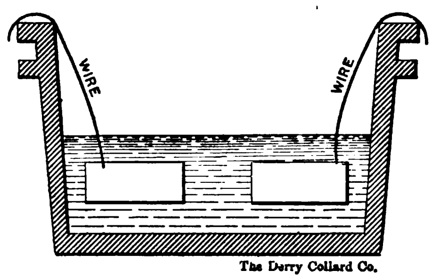
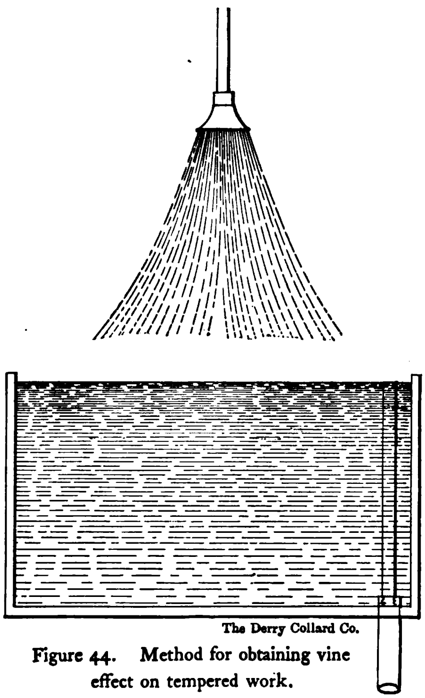


Figure 43. Heating in cyanide for colors.

When colors are wanted, articles made of tool steel may be suspended in the molten cyanide by means of wire hooks, which pass over the edge of crucible, as shown in Fig. 43. When the article becomes heated to a uniform heat, it may be removed and plunged in a tank of water, working it around well until cold, when it may be removed and dried. If it is desirable to draw

the temper and yet retain the colors, it may be done by heating in a kettle of oil, guaging the heat by a thermometer. The work must be left in the oil, away from the action of the air, until it is cooled below the point where temper colors are visible.

This method of hardening is used very extensively in gun shops to harden gun frames, and at the same time procure the beautiful colors often seen on them. It works equally well on machinery steel or malleable iron. It is accomplished by attaching a piece of wire bent in the shape of a hook to the frame, the other end of the hook hangs over the upper edge of the crucible. It is necessary to have the article entirely under the surface of the cyanide. When it is heated for a sufficient length of time, which must be determined by experiment, it may be removed and plunged in a tank of water. In order to produce the



The Derry Collard Co.

Figure 44. Method for obtaining vine effect on tempered work.

beautiful vine-like effect often noticed, the inlet pipe may be situated about two feet above the tank, as shown in Fig. 44. The end of the pipe may be made to spray the water. The articles when taken from the cyanide crucible should be passed through the spray into the bath. Wherever the fine spray strikes, it produces the vine-like effect mentioned. The colors may be guaged by the heat given the contents of the crucible, also by the temperature of the bath.

After using, a hook must be thoroughly dried before putting in the molten cyanide, as the presence of moisture, even in the most minute quantities, will cause the cyanide to fly. If it strikes the flesh, it produces a burn, which, on account of the poisonous nature of the chemical, is liable to be very sore, but by avoiding the presence of any form of moisture, this need not occur.

Articles made of malleable iron, as cutters for paper, and wood, may be hardened by heating in this manner. If only a few pieces are to be hardened, the cyanide may be heated in an iron dish of suitable size, the articles suspended in the dish until heated sufficiently, when they may be quenched in a bath of cold water, or warm water, according to the nature of the work to be done. Should this prove to make them too hard, a bath of tallow or oil may be used.

Articles made of machinery steel may be heated in the cyanide crucible for hardening, the amount of hardness and depth which it penetrates depending on the amount of heat given and the length of time the article is left in the cyanide.

If the articles are of a size that warrants it, they may be suspended in the cyanide by means of wires, as previously explained. If they are small and there

are many of them, they may be placed in baskets made of wire cloth and suspended in the molten mass. These baskets should not, however, be made of galvanized wire, or have any solder used in their construction, or the articles will be coated with lead. Care must be exercised when placing the articles in the basket, not to put in too many, especially if the basket is to be dipped into the hardening bath, as the pieces would touch each other when in the water; consequently they would not be hard at these points.

When it is desired to make articles other than cutting tools, and harden them throughout, it may be done by procuring a low grade steel, sufficiently high in carbon to produce the desired result. The steel may be either Bessemer or open hearth. If hearth steel, the temper must be suited to the particular purpose it is to be used for. When the article is ready for hardening, it may be suspended in the molten cyanide; when it has heated for a sufficient length of time, it is removed and plunged in the bath. If hardness is the only quality desired, use a bath of water. If a hard surface is desired, and a very tough, strong interior, use a bath of oil and tallow.

Malleable iron may be hardened by heating in cyanide of potassium, as is the case with machinery steel, the depth of hardening depending on the length of time it was left in the cyanide. If colors are desired, the surfaces must be polished, and a bath of clean water used. If a strong, tough effect is desired, quench in oil.

It is sometimes desirable to color a piece of work in imitation of case hardening, yet leaving the article soft. If the piece is made of machinery steel of low

carbon, or of malleable iron, this is accomplished by using a cyanide made especially for the purpose. This is known as "50 per cent. fused cyanide of potassium."

Hardening Steel.

Having considered the nature of steel, methods of heating for different purposes, and the means of cooling by the various baths, we will proceed to the consideration of hardening articles of various types. As it would be impossible to consider all the articles that require hardening in the various shops throughout the country, such examples have been selected as are representative of the articles that are commonly hardened.

Uniform heats are the secret of success when hardening steel. A greater part of the trouble experienced by men not skillful in this branch of the business arises from this fact not being observed. The writer cannot resist the desire to caution the reader against trouble arising from this cause, and hopes he will be pardoned if he apparently repeats this warning oftener than may seem necessary.

When hardening steel, avoid too rapid cooling of the surface, as it is then rigid and inflexible, while the inside of the piece is still undergoing the change in structure incident to hardening. As a consequence, if the outer surface is hard and inflexible, and the internal portion is undergoing changes in size and structure, the outer surface will crack from the enormous strain brought to bear on it. It is advisable when hardening

small articles to heat the contents of the bath somewhat, to avoid the sudden cooling mentioned.

As stated, when the surface becomes hard before the center has ceased changing its size and structure, there is a tendency to crack the surface from the internal strains.

To overcome this tendency, the piece should be heated to a degree that allows the surface to yield somewhat and conform to the strains in the piece. The amount of heat necessary to produce this result has been ascertained to be at the temperature of boiling water (212 degrees). An experienced hardener can determine the necessary amount of heat very nicely by the sense of feeling, heat the steel until, when touched with the moistened finger, the peculiar snapping sound is heard. This is the same as the housewife tells when her irons have reached the proper temperature for ironing linen.

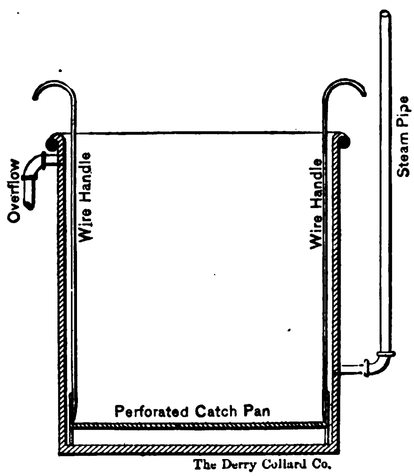


Figure 45. Bath for hardening in hot water.

When pieces are hardened in large quantities, it becomes very costly practice reheating each piece over the fire, guaging the heat by the sense of feeling. A

good plan in such cases is to have a tank of the description shown in Fig. 24. A steam pipe is connected with the tank, as by this means it is possible to heat the water to any desired degree to the boiling point. A perforated pan is provided to catch the work as it is dropped into the tank. Occasionally the pan may be removed from the tank by means of the wires shown, the pieces emptied out and the pan returned.

As the pieces are removed from the hardening bath, they may be dropped into this tank, and the tendency to crack overcome. For certain articles the brittleness is reduced sufficiently, making it unnecessary to draw the temper any more.

The use of extremely cold baths is not as a rule advisable. Results fully as satisfactory so far as the hardened surface is concerned, are obtained if the bath is warmed somewhat, and the danger of cracking is greatly reduced.

It is claimed that when articles made of steel and heated red-hot are plunged in a cooling bath, the outside surface becoming chilled and consequently contracted, causes by this process of contraction an immense pressure on the internal portion of the steel which is red-hot; this pressure has the effect of raising the temperature of the interior of the steel still higher, with the result that it expands still more. This extra expansion is, of course, communicated to the hardened (and consequently unyielding) surface, and this being unable to stand the immense strain, either cracks or bursts.

If the contents of the bath are heated to some extent, the surface is not chilled below a temperature that allows it to yield somewhat, allowing it to con-

form in a measure to the internal pressure, which is relieved as that portion cools and contracts.

The pliability of steel when warmed is illustrated in the case of such tools as taps, reamers, or drills, which become crooked when hardening. In order to straighten, it is necessary to apply a certain amount of heat. Place the tool between the centers of a lathe, with the convex side toward the operator, a piece of stock is then put in the tool post of the lathe, having one end against the bowed side, as shown in Fig. 46. The article is now heated until oil placed on the surface commences to smoke; pressure is applied by means of the cross feed screw and until the article is slightly bowing in the opposite direction.

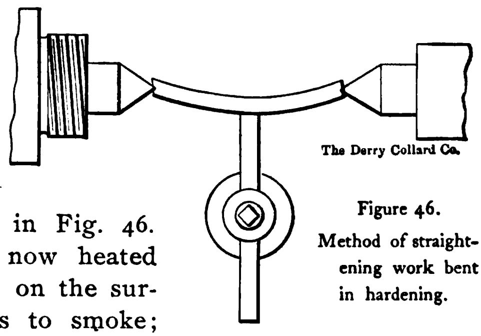


Figure 46.
Method of straightening work bent in hardening.

The piece should now be suddenly cooled while in this position. If it is not straight, the process should be repeated. Now, it is safe to spring the steel when warm, but when it is cooled, even after heating, as described, it will break if any great amount of pressure is applied. Should it spring somewhat when cold, it will return to its original shape when the pressure is removed, thus proving that hardened steel, when heated to a certain degree, is somewhat pliable. It is for this reason the surface of a hardened piece is reheated to "remove strains," as it is familiary termed,

or it is made pliable by heat, and in this condition conforms to the immense strain incident to hardening.

In the case of the article heated and straightened by pressure, it is necessary to cool the piece uniformly. Should one side be cooled and the opposite side left hot, the piece would probably crack from the unequal contraction. By carefully following this plan it will be possible to save many tools that would otherwise have to be thrown away—or which, if used, would not be satisfactory.

Drawing the Temper after Hardening.

When a piece of steel is hardened it becomes brittle. When the design of the piece is such that the working surface has sufficient backing, it is safe and advisable to keep the article as hard as when it comes from the bath. But in the case of tools having slender cutting edges, as taps, screw threading dies and milling machine cutters of the ordinary styles, it becomes necessary to reduce the amount of brittleness in order that it may stand up when in use. This is done by reheating the piece somewhat.

The process of reheating also has the effect of softening the steel to a considerable degree. It is not generally desirable to soften it, but it is necessary to do so in

order to reduce the brittleness. This reheating is generally termed "drawing the temper." Unfortunately, the word temper is understood as having more than one meaning, and as a consequence people are sometimes puzzled to know exactly what one means when the term is used. By some it is understood as the double process of hardening and drawing the temper. To others it simply conveys the idea of drawing the temper of a hardened piece, and will be so used by the writer in connection with treating steel by heat, although the steel maker's definition of the word temper will be used occasionally to designate the percentage of carbon the steel contains.

When steel is heated, the amount of heat it absorbs may be determined by the surface colors, provided it has been brightened previous to heating. It is customary after hardening to brighten the surface with a stick whose surface has been coated with glue and then covered with emery, or a piece of emery cloth may be attached to a stick or held on a file. After brightening, the piece may be subjected to heat. As the steel becomes heated various colors will appear on the brightened surfaces. The first color visible is a faint straw color, then straw color, light brown, darker brown, brown with purple, light blue, darker blue. If heated to a black, the hardness is reduced to a point that makes the steel practically soft.

The amount of heat necessary to give steel in tempering, depends on the make of the steel, how hot it was heated when hardening, and for what purpose it is to be used. The method ordinarily practiced has been briefly described above.

When work is done in large quantities, the temper

is sometimes drawn by placing the articles in a pan having a long handle, as shown in Fig. 47. A quantity of clean sand is put in and the pan held over a fire, moving it back and forth, thus keeping the sand and work in motion. The surface colors can be closely watched and excellent results obtained. If there are any sharp edges or cutting teeth that will be harmed by striking against the other pieces, it is not advisable to use this method unless extreme care is exercised, but a pan of sand may be placed over the fire and a few pieces of work, having edges as described, placed in it and kept in motion by a stick, being careful not to hit them together.

An excellent furnace, which is illustrated in Fig.

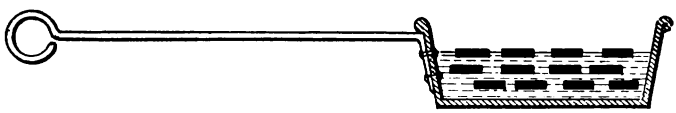


Figure 47. Pan for drawing temper.

48, can be procured, which gives very satisfactory results. The pieces to be tempered are placed in the pans, D D, which rotate at the speed of two or three revolutions per minute, the pans being hung loosely from rods connected with spokes around the driving block in the center, which receives motion from the worm and gear, A B, connected with power. The door, C, is closed and the furnace is charged with work, and may be opened for observation. When opened, the door forms a shelf or rest for the pans.

The thermometer indicates a degree of temper somewhat different from the actual heat in the furnace, but if the temperature indicated is observed when the desired temper is obtained, the operation may be repeated with satisfactory results.

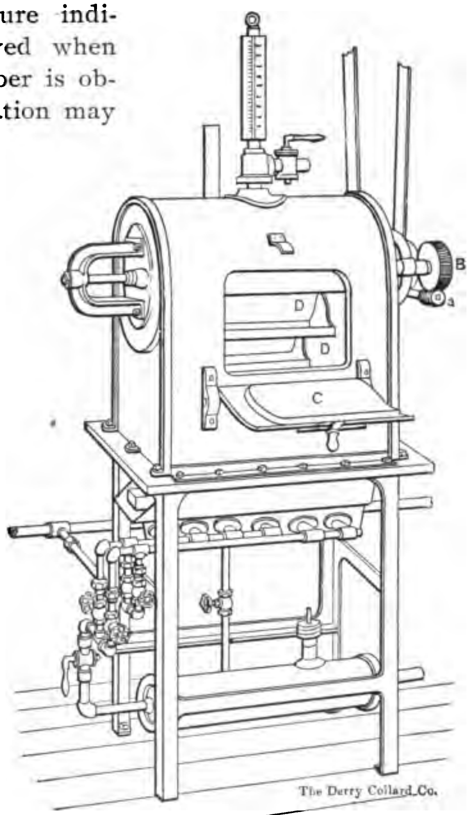


Figure 48. Revolving furnace for tempering small pieces.

This furnace is designed for tempering small articles, but the writer has used it with excellent results on punches used for punching rectangular holes 2 inches by 5/8 inch, the shanks being 1 1/4 inches in diameter and 5 inches long. The action of the furnace depends on the heated air, with temperature so regulated that articles of irregular shape can be exposed to it long enough to impart the proper temper to the heavier parts without drawing the temper too low on

the lighter parts of the same piece. By means furnished of regulating the heat generated, the injection of the heat evenly throughout the furnace is easily secured, and the overheating of any part of the piece prevented.

A common method when drawing the temper of articles which are of a uniform thickness, is to heat a flat piece of iron to a red heat, lay the pieces on this, moving them around and turning them over occasionally to insure uniform heating. When the desired temper color shows, the piece is immediately immersed in oil to prevent its softening more than is desired. This method is open to objections when articles having heavy and light portions, which must be heated alike, are to be tempered, because the lighter parts, heating more quickly than the heavy ones, will become too soft before the heavier portions reach the desired temper.

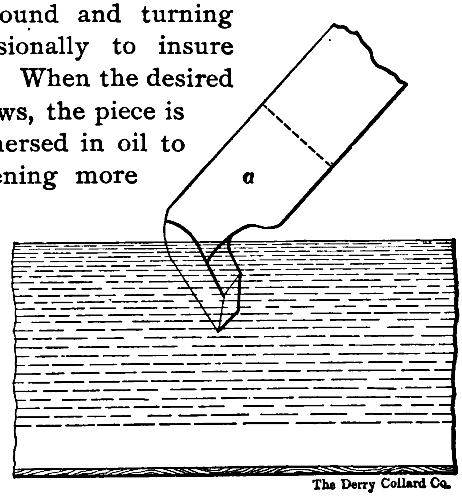


Figure 49. Hardening a diamond pointed lathe tool.

When tools having heavy parts adjoining the cutting portion are to be hardened, and it is not necessary to harden the heavy parts, as a diamond point lathe tool or similar article, it is the general practice to heat the tool for a distance on the shank—say as far back as

the dotted line in Fig. 49—to a red heat. Plunge the cutting blade into the bath, being careful not to dip the portion marked *a* into the bath. Work up and down to prevent a water line, and move around to avoid steam. When the cutting part is sufficiently hardened, remove from the bath, and allow the heat from the heavy portion to run into the hardened part until the desired color shows, when it may be quenched to prevent its running any lower.

When work is tempered in large batches, a very satisfactory method consists in putting the articles in oil and heating to a proper degree, gauging the heat by means of a thermometer.

A very satisfactory tempering furnace is shown in Fig. 50. Illuminating gas is used as fuel. The burning gas circulates around the kettle holding the oil, thus heating it very uniformly. The work is held in a perforated pail or basket, somewhat smaller than the inside of the kettle. The degree of heat to which the oil is brought is shown by the thermometer.

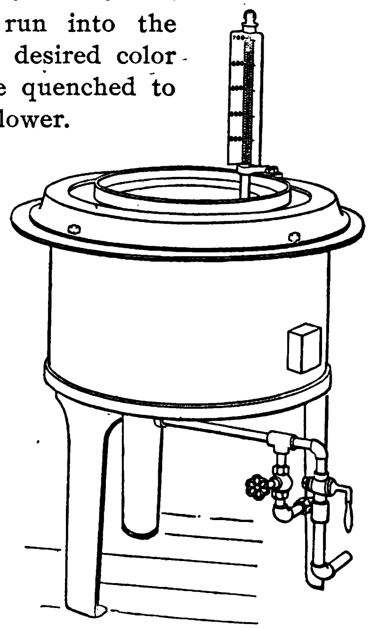


Figure 50. Oil tempering furnace.

If not situated so that a furnace of this kind is accessible, a kettle may be placed on a fire in a black-

smith's forge and built up around with bricks, leaving a space up around the kettle for coals. Now fill the space with charcoal. As this catches fire, it heats the oil in the kettle. The articles to be tempered may be placed in the perforated sheet iron pail, at least two inches smaller than the inside of the kettle. The pail should have a flange at the bottom, as shown in Fig.

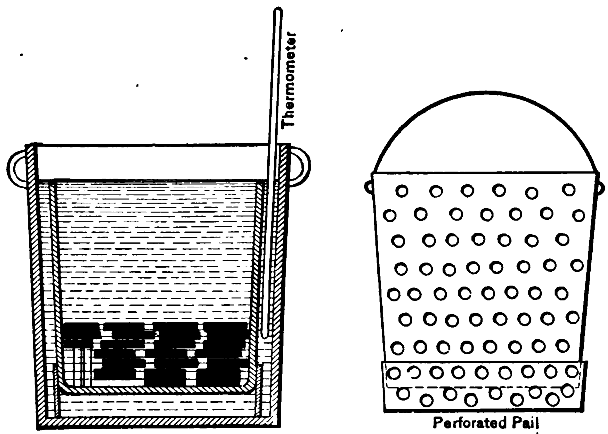


Figure 51. Oil tempering in a kettle.

51, or it should be blocked up 1½ inches or 2 inches from the bottom of the kettle, to allow the oil to circulate freely beneath it.

If the pail were to rest directly on the bottom, the pieces of work at the bottom of the pail would soften too much from coming in contact with the kettle, which is acted on by the direct heat of the fire. The thermometer should be placed between the pail and the

kettle, as shown. It is advisable to stir the oil in the kettle occasionally, in order to equalize the heat. When the thermometer shows the desired degree of heat, the pail containing the work may be removed, set to one side, where no current of air can strike it, and allowed to cool off.

When pieces of hardened steel are placed in a kettle of oil and heated, the temper colors do not show, so it becomes necessary to gauge the heat by a thermometer. The temper colors are significant of a certain amount of heat which the steel has absorbed.

Faint straw color	430	degrees	Fahr.
Straw color	460	"	"
Light brown	490	"	"
Darker brown	500	"	"
Brown with purple spots	510	"	"
Light purple	530	"	"
Dark purple	550	"	"
Light blue	570	"	"
Darker blue	600	"	"
Blue, tinged with green	630	"	"

Knowing the proper degree of heat to which a piece of steel should be subjected, it becomes possible to draw the temper on any number of pieces exactly alike, and much more uniformly than though they were gauged by color. As stated, 430 degrees of heat represents a faint straw color, while 460 degrees a full straw, a difference of only 30 degrees, yet when tested with a file by one accustomed to this work, there is a vast difference in the hardness of the two. While the difference in the two colors is slight, yet difference in the ability of the two pieces to resist wear in the case of

cutting tools is quite noticeable. The average man does not detect a difference of 10 degrees by observing colors, consequently he is liable to have a product varying in efficiency if he attempts to draw the temper by observing the color. But if he gauges the temper by a thermometer he can get his product within a limit of 1 degree or 2 degrees every day, and at a much less cost than if he were to draw to the color, provided the work is done in large quantities.

At times a tool as it comes from the bath is too brittle to stand up well, yet when the temper is drawn to the first color discernible, *i. e.*, a light straw—it is too soft to do its maximum amount of work. Now, in a case of this kind the temper may be drawn to 200 to 250 degrees, or any temperature that proves exactly right.

The writer has in mind tools which, if left dead hard, would crumble away on certain projections when used; but if they were heated to the faintest straw color, would not do the amount of work required of them. But if they were taken from the hardening bath and placed in a kettle of boiling water (212 degrees) and left there about five minutes, would show excellent results when used. Other tools showed best results when heated to 300 degrees and some to 350 degrees. These facts are given the reader in order that he may understand that there is a method whereby the amount of brittleness in a piece of steel may be reduced to a point where it will stand up to its work and yet not soften it as much as is necessary when it is drawn to the first temper color discernible.

The colors visible on the brightened surface of a piece of heated steel are supposed to be due to a thin

coating of oxide, formed by the action of the air on the heated surface. If a piece of steel is heated in oil away from the air, these colors will not present themselves, provided the steel is left in the oil until the temperature is below the point necessary to show the faint straw color (430 degrees).

It is necessary, in order to gauge the temper to which steel is drawn if gauged by temper colors, not only to have the piece bright, but it must be free from grease or oil, as the presence of oil will cause the colors to show differently than if the surface were clean.

It is the custom in some shops to polish the hardened pieces and then draw the temper leaving the temper color as a finish. Now, if the work has been polished on a greased wheel, a certain amount of the oil is taken into the pores of the steel. When it is heated in tempering, this oil comes to the surface of the steel and produces a peculiar appearance. The surface appears streaked. If it is wiped with an oily piece of waste or cloth, this streaky or mottled look disappears. Many hardeners always wipe a piece of steel being tempered with some substance having oil or vaseline on it; the appearance of the temper color is slightly changed by so doing, but allowance is made for this.

When drawing the temper of articles which are small or thin, it is not advisable to heat by rapid methods, heating until the desired color appears and then quenching in cold water to keep it from running too low. The cold water, on account of the sudden chill which it gives an article heated to 430 to 500 or more degrees, has a tendency to make it more brittle

than it would be if it were drawn to the proper temper color and allowed to cool off slowly, or plunged in warm oil or hot water. In the case of large, heavy pieces, or where brittleness would do no particular harm, this precaution need not be observed so closely. But on the other hand, if brittleness did no harm, it would not be necessary to draw the temper, because few tools are ever too hard for the purpose for which they are intended. For, as previously explained, the process of hardening makes them too brittle to stand up well when they are in use, consequently they are tempered to reduce the brittleness to a point where they will stand up. But the process of tempering is also (unfortunately for cutting tools) a process of softening.

It should be the aim of the hardener at all times to harden steel at the lowest heat that will give the desired result, because in this condition the steel is the strongest possible, and consequently will not need the temper drawn as much as though it was given a higher heat and made brittle. Many times the writer has seen hardeners heat a diamond point turning tool to a temperature much hotter than was necessary when hardening, then draw it to a full straw color in order to reduce the brittleness so it would be able to cut and not flake off, or the surface cave in when the tool was cutting.

Now, the tool in this condition could not do anywhere near its maximum work in a given time. Neither would the life of the tool be as long as though it were hardened at the proper heat, and in this case it is doubtful if it would be necessary to draw the temper at all, provided it had not been improperly heated when forging. Many times tools of this description

can have the temper drawn sufficiently by immersing the tool after hardening in a dish of boiling water and leaving there a few minutes.

Examples of Hardening.

When hardening articles made of tool steel, it is necessary to consider, first, the nature of the steel used, the construction of the article, next the shape of the article, and the use to which it is to be put. It is also necessary to take into consideration the means of heating furnished by the shop, and the bath to be used in quenching the article after it is heated.

The operator should adapt himself so far as possible to circumstances as he finds them, although it is not advisable to attempt the impossible, because a failure is generally counted against the man making it, rather than to any lack of apparatus necessary to do a job successfully. By this is meant that it is not policy to attempt to heat a piece of steel for hardening in a fire that cannot be made to heat the piece the entire length under *any* conditions—that is, if it is necessary to harden it the entire length—because such an attempt must end in a manner disastrous to the steel. It is, however, the best plan to attempt to find some means whereby the piece may be heated properly by means of the apparatus at hand.

The writer remembers, when a boy, seeing a tool

maker heating a long taper reamer. The only means of heating furnished by the shop was an ordinary blacksmith's forge. By building a large, high fire he was not able to do a job satisfactory to himself, so he cleaned the fire out of the forge, and then took some fire brick,

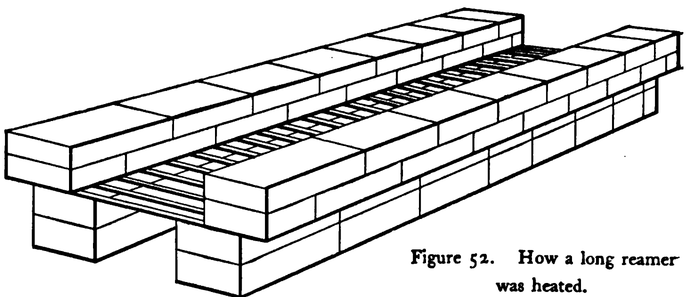


Figure 52. How a long reamer was heated.

placing two rows on the forge, as shown in Fig. 52. On these he placed pieces of wire, about one-half inch apart, built two rows of bricks on top as shown, thus forming an oven, and then built a fire of charcoal on the wires between the bricks. By standing bricks up at the openings at the ends, he was enabled to get a very good fire in which he heated the reamer in a very satisfactory manner.

While it would not have been wise to have pursued this method of heating, if there had been many pieces of the kind mentioned to be hardened, yet the fact that this man was able to adapt himself to circumstances and devise a way of doing a seemingly impossible thing, made him a valuable man in the estimation of his employers. It is the man who can do the seem-

ingly impossible things about a shop that is looked upon as the invaluable man, and it generally counts, as would be seen if his pay envelope was examined.

While it is advisable, whenever possible, to study up some way of doing the work, do not attempt the impossible unless some one over you in authority assumes the responsibility. It is better to acknowledge your lack of ability than to spoil a costly piece of work, when it would have been considered advisable by those in authority to have sent the article to some one having the necessary equipment, had their attention been called to the matter.

Cases like this may often be used to good advantage in pointing out the advisability of securing better facilities for hardening and tempering. As long as it is possible to get along without any equipment but a common blacksmith's fire, it is often very hard to obtain anything better.

Hardening Dies.

If it is necessary to heat a large die in an ordinary blacksmith's forge, it can be done. It is done right along by men who have had years of experience, and very satisfactory results are obtained. The writer knows a man who is considered a very successful hardener. He does very little else but hardening large drop forging dies. He heats them in an open fire and has very good success. He could have, were he to ask for it, the very best equipment that money could buy, but he prefers heating by the method mentioned.

The writer also knows of an old man who lives

Poor scheme to heat in blacksmith's forge.

four or five miles from the city. The electric cars run within five hundred feet of his house, but rather than ride on "them air new fangled devil's contraptions," as he calls them, he walks to the city, unless some of his neighbors give him a ride in their carriage. It may not seem to be a parallel case. If it isn't, the odds are in favor of the farmer, as there may be a certain danger in riding in the trolley cars.

Now, it is possible to heat a large piece of steel, such as a drop forging die, in a blacksmith's forge by building a large, high fire of charcoal, placing the die on this, making certain that the face is buried in the live coals to a depth of several inches. It would be necessary to raise the die occasionally and work the coals under it, as it would not do to allow the air from the blast to strike the face. It is very necessary to heat the face uniformly. In order to do this it may be found necessary to move the die, so that some part that is heating slowly may be placed in a position where it will get more heat.

Now, while it is possible to heat work of the description mentioned by the method described, it is not policy to do it, provided any other means is at hand, or can be procured—that is, if there are many pieces to be hardened. If there are but one or two pieces, it is possible by using extreme care to get good results; but if there are many of them it is folly, speaking from a commercial standpoint, to heat by this method.

A furnace which gives very good results may be made, if it is not considered advisable to purchase one especially adapted to this class of work. Fig. 53 represents a muffle furnace burning hard coal as fuel, although charcoal or coke may be burned; but it will

be found easier to maintain a uniform heat by the use of hard coal, and as the products of combustion do not come in contact with the piece being heated, they cannot in any way harm it. A represents the muffle which receives the work. This is located directly over the

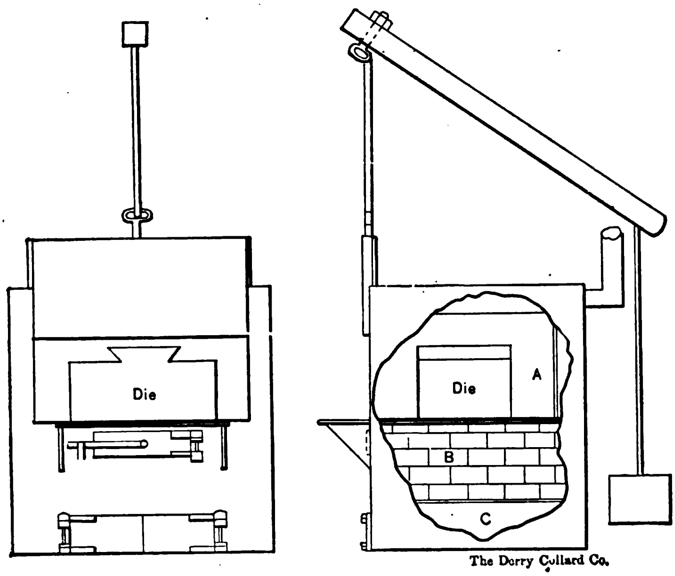


Figure 53. "Home-made" furnace for die work.

fire box B. The heat and gas from the fire pass up the sides and back of the muffle, thus insuring a very strong heat. The ash box C is provided with a door which has a sliding damper to furnish a draft for the fire. The smoke pipe is connected with the chimney. This is also provided with a damper to use in controlling the fire.

The die may be blocked up from the bottom by

means of several pieces of iron or fire brick to prevent the face coming in direct contact with the floor of the muffle. The door of the muffle should have an opening, which should be covered with a piece of mica in order that the heat may be readily observed without cooling the die.

When many very large, heavy dies are heated it is advisable to have the bottom of the muffle on a level with the floor, sinking the fire box and ash box in the ground. By having the muffle on a level with the floor it is not necessary to raise the die in order to get it into the muffle. When it is not considered advisable to do this, an iron platform may be built on a level with the bottom of the muffle. The heated die may be run out on this and then taken with tongs or grappling hook and carried to the bath.

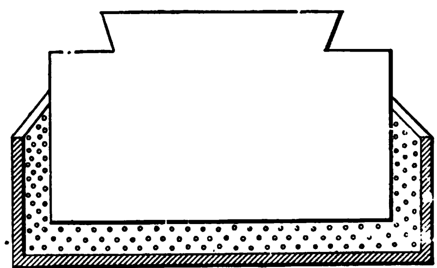


Figure 54. Box for heating dies in charred leather.

Other forms of furnaces which may be used for this purpose are illustrated under the section showing Methods of Heating.

It is customary with some manufacturers who make a great many dies to harden them in the following manner: Take a box 2 or 3 inches longer and wider than the die, and 4 or 5 inches deeper. Put in about 2 inches

of granulated charred leather, place the face of the die on this, as shown in Fig. 54, then fill the box with leather.

Some hardeners use a box large enough to take in the whole die and allow for a cover on top. It is then entirely removed from the action of the fire, even if heated in a furnace where the work is placed directly in the fire. But as it is not possible to get a test wire down through the center of the die; and a wire at the sides of the die would not show the amount of heat the die contained, and as there would be no means of observing the heat, the operator would have no means of knowing whether the die was too hot or not hot enough, or whether it was heating uniformly. And as the decarbonization of the surface of the upper part of the die is of little consequence, the plan suggested by Fig. 54 will be found the most satisfactory, as the heats can be watched and the die moved occasionally in order to equalize the heat, which is apt to be greater in one part of the furnace than in another. The furnace should not be heated much above the temperature desired for the die. It is better to take a longer time in heating than to heat unevenly, thereby setting up strains which are bound to manifest themselves when a piece is hardened, or if they do not at that time they will shortly afterward.

When the proper heat has been obtained, the box may be removed from the furnace and the die taken out and plunged into the bath. The form of bath used for this class of work differs, some hardeners preferring one with a jet of water coming up from the bottom, as shown in Fig. 55. This works very nicely if the impressions are not too deep, in which case the

steam formed has a tendency to rise in the impressions and keeps the water from going to the bottom. When dies of this description are to be hardened, a bath may be constructed with an overhead pipe, as shown in Fig. 56. By this means the die is placed on the rods shown, and when the water is turned on it will go to the bottom of any impression that would be likely to be in any die. This form has the further advantage that a cupful of strong solution of salt and water, potash and water, or cyanide of potash and water may be dashed on the face and into the impression just ahead of the jet of water. This has the effect of starting any scale that may have been formed after the die was exposed to the air.

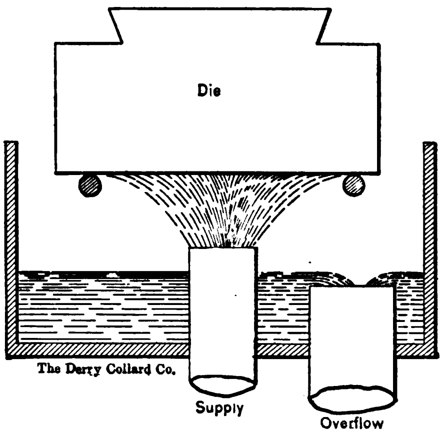


Figure 55. Bath for hardening dies.

Some hardeners have rods in the bath for the face of the die to rest upon, as shown in Fig. 55, then allow the jet to play against the face, while others claim better results if the die is worked up and down somewhat in the bath as described.

It is customary with many manufacturers who

have many dies of this character to harden, to use a bath having an inlet pipe coming up from the bottom, as just shown. When the die is properly heated, it is placed on the rods with the dovetailed tongue down; the stream of water is allowed to play against this side of the die until it is somewhat cooled; this not only prevents this portion springing when the face is hardened, but it allows the heat to run to the face of the die.

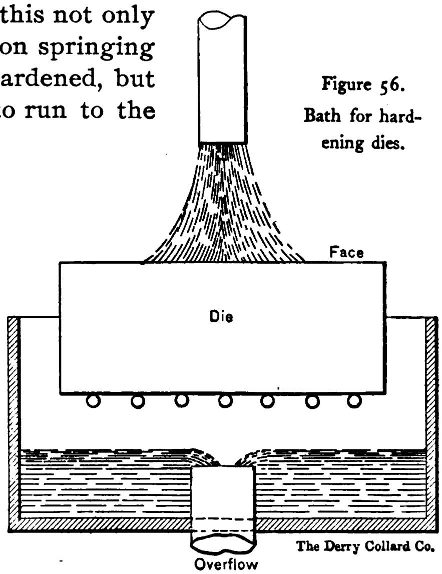


Figure 56.
Bath for hardening dies.

After the tongue side is sufficiently cooled, the die is turned over and the stream of water is directed against the face; the overflow is checked sufficiently to allow the water to rise several inches above the face, on the sides of the die; that is, it is immersed several inches in the bath; the depth of immersion depending on the character of the die and the custom in the individual shop.

When dipping large, heavy dies in the bath, it is advisable to hold the die with a pair of grappling hooks, as shown in Fig. 57. These should be attached to a rope or chain and operated by a pulley, in order

that the die may be raised and lowered somewhat in the bath. Then again, it would not be advisable for the workman to dip so large a piece of steel with tongs that necessitated holding his hands and arms over the bath, as the immense volume of steam would be liable to burn him; neither could he properly support the die in the bath.

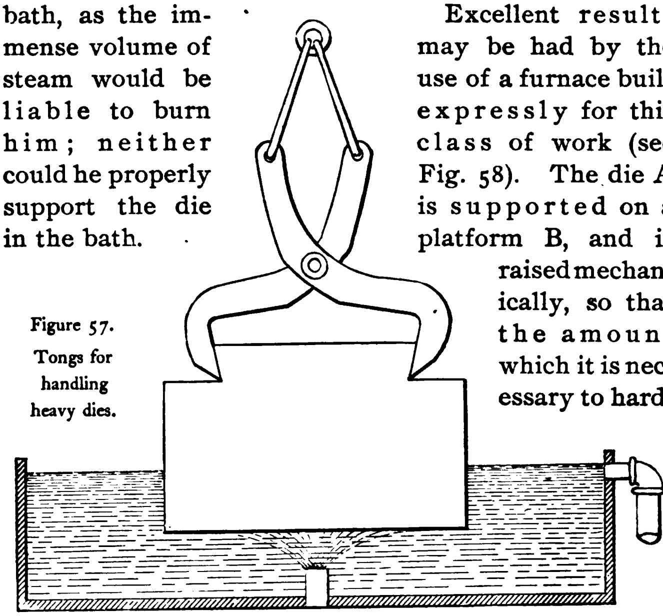


Figure 57. Tongs for handling heavy dies.

Excellent results may be had by the use of a furnace built expressly for this class of work (see Fig. 58). The die A is supported on a platform B, and is raised mechanically, so that the amount which it is necessary to harden is in the furnace, while the rest of the die is below and removed from the action of the heat. The heating chamber is on top, with burners entering opposite sides and projecting the flame against the top lining and distributing it evenly. The die should not be placed on the platform until the furnace is evenly heated, when it may be raised by means of the lever D, until the face enters the furnace the desired amount. The face of the die can be observed through the open-

ing C. When heated to the desired degree, the platform is lowered, the die withdrawn and quenched. The weight of the die is counterbalanced by the weight shown, which can be shifted as occasion requires.

Dies used in making molds for hard rubber and similar work, whose faces are engraved, may be packed as described and represented in Fig. 54, and run until the required heat is attained. After the heat becomes equalized—*i. e.*, the same throughout—the die may be dipped in the bath of brine, using the arrangement shown in Fig. 57. It is necessary to get the die in the bath as soon as possible after removing from the packing material in order to prevent oxidation of the face containing the engraved work.

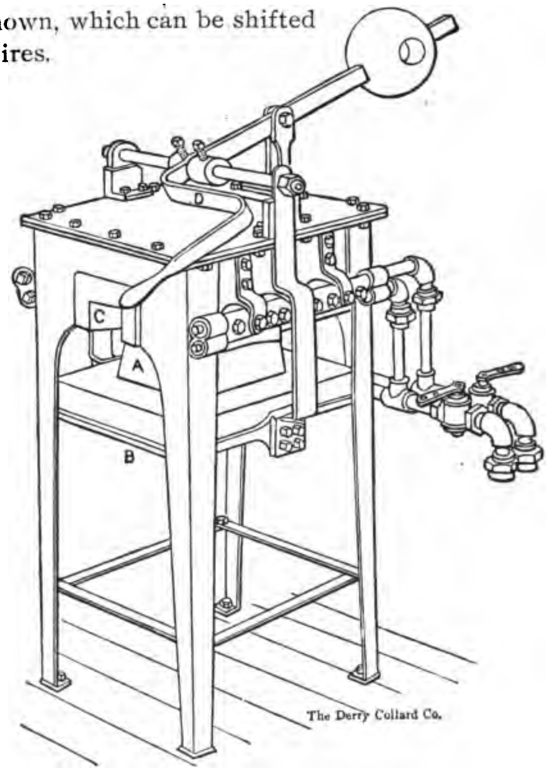


Figure 58. Gas furnace for heating dies.

Punching press dies.

Dies for punch press work, especially those used for blanking—that is, punching blanks from sheet or other stock—occasion a vast amount of trouble in many shops when they are hardened. Observation has led the writer to believe that most of the trouble is caused by *uneven* heats. The corners and edges of the block and the edges surrounding the openings will heat much more rapidly than the balance of the die block unless extreme care is used.

Before putting the die in the fire, all screw and dowel pin holes and holes for guide pins (stops) should be filled with fire-clay, mixed with water to the consistency of dough. This prevents the contents of the bath entering the holes, and reduces the tendency to crack. The die should, if possible, be heated in a muffle furnace, not heating the furnace much, if any, hotter than the desired heat for the die. When it is to the proper heat and uniform throughout, remove from the furnace, catch by one end with a pair of tongs and lower into a bath of brine. Swing slowly back and forth in the bath, in order that the contents of the bath may pass through the openings. This insures the hardening of the walls, as otherwise the steam generated would force the contents of the bath away from the die until it had cooled to a point where it would not harden. When the die ceases to sing, it may be removed and plunged into a tank of oil.

There is not much danger of a die cracking when dipped in a bath, provided it was annealed after the blank had been machined all over and the openings blocked out somewhere near to shape. But it is extremely essential that the utmost care be taken when heating for hardening. Be sure that no part of the die

block is heated any hotter than it should be. The heat *must* be uniform throughout the piece. If the shape is one that betokens trouble, it is advisable to heat the contents of the bath considerably. Generally speaking, it is not advisable to use an extremely cold bath on this class of work.

The writer prefers using a tank of generous proportions, so the contents would not be materially affected by the heated piece, and heating the liquid to a degree that does away with any tendency to crack the piece. An excellent method to prevent the tendency to crack from internal strains, consists in placing the die, after hardening, in a kettle of boiling water, keeping the die in the water at this temperature for one or more hours, according to the size of the die.

If the temper is to be drawn immediately after the die is taken from the bath, a flat piece of cast iron or scrap steel may be heated while the die is being heated, and quenched. It is customary with some hardeners to heat the piece red-hot. Brighten the face of the die and lay it on the heated iron. The die should be moved around on the heated piece and turned over occasionally to heat both sides alike. When the temper has been drawn the desired amount, the die may be immersed in oil, thus preventing the temper being drawn too much.

While it is the custom of many hardeners to heat the drawing plate red-hot, as explained, before placing the die on it, the writer considers it better practice to heat the plate *somewhat*, leaving it over an open fire. Place the die on the plate and gradually raise the heat. It is rather rough treatment for a piece of unyielding hardened steel to be brought in direct contact with

extreme heat, and is liable to crack the surface of the steel in innumerable places, especially if the operatoı is not thoroughly experienced in this line of work.

The amount necessary to draw the temper of a blanking die depends on the steel used in its construction, the temperature it was heated to when hardened, and the nature of the work to be performed by it.

Generally speaking, it is advisable to refer the matter of how hard the die or punch should be to some one familiar with the requirements of the work to be done. In *some* cases it is desirable to have the punch the harder of the two, although, generally speaking, the die is left harder than the punch. In some shops, the one that requires the greater expense in making is left the hardest, in order that it may be the least injured in case they strike together when in use. In such cases it is necessary to draw the one that is desired softest considerable lower than the other.

But as the circumstances must govern the relative hardness of the two, no hard and fast rule can be given.

It is customary to draw to a temperature varying from that which produces a faint straw color, to a brown with purple spots.

Probably no one class of tools used in machine shop work requires greater care on the part of the hardener than the hardening and tempering of punches and dies; and probably no class of tools involves a wider range of methods of hardening and degrees of hardness essential to produce desired results in the individual shop.

The hardener who is desirous of giving satisfaction will study the conditions in the shop where the tools are to be used. He will also consider the steel

used in the construction of the tools and the nature of the stock to be machined. It will be necessary also to get the experience of men familiar with the work to be done, because a die and punch hardened and tempered in a manner that insured satisfaction in one shop would not meet the requirements in some other shop.

When hardening the punch, use extreme care in heating. If the punch is strong and is to be used for punching comparatively light stock, it is not necessary to harden it the entire length. Take, for instance, the punch shown in Fig. 59, to be used for punching sheet steel $\frac{1}{16}$ inch thick. This will work satisfactorily if hardened to the dotted line shown.

When, however, it is necessary to harden a piercing punch of the design shown in Fig. 60, it will be found necessary to harden the entire length of the end *a*, if the punch is to be used on heavy stock. Should

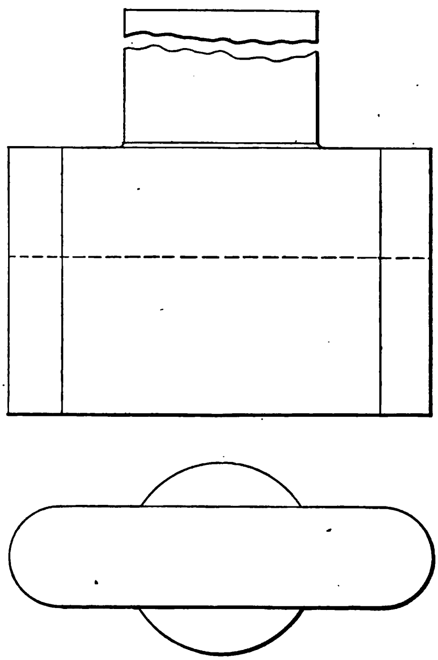


Figure 59. Punch for $\frac{1}{16}$ inch steel plates.

the hardness extend only to the dotted cross line, it would buckle, as shown in Fig. 61, when punching stock as thick as the diameter of the punch.

When making punches that are heavy and strong, and which must retain a good edge, it is advisable to use a steel of comparatively high carbon. But if

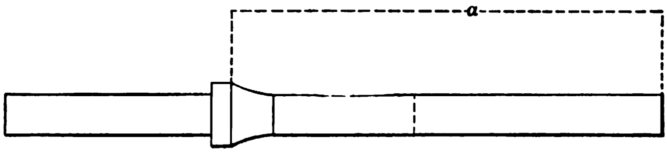


Figure 60. Piercing punch for heavy work.

punches are made of the form shown in Fig. 60, best results will follow if a comparatively *low* carbon steel is used, as it is not as liable to crystallize as if a higher

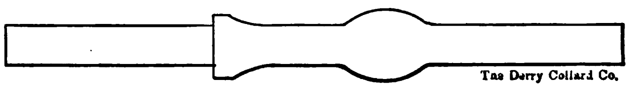


Figure 61. Result of hardening only as far as the dotted line, as shown in Figure. 60.

steel were used. As a rule, drill rod does not give good results when used in making tools of this description.

When punches are sufficiently strong, it is advisable to apply the heat at the shank end when drawing the temper. A block, as shown in Fig. 62, having several holes a trifle larger than the shanks of the punches may be heated red hot and the punches placed in these holes. When the desired temper color is visi-

ble at the cutting end, the punch may be taken from the block and dropped in oil to prevent its becoming too soft. The upper end of punch will, of course, be softer than the cutting end.

When a long, slender punch, of the design shown in Fig. 60, is to be tempered, and the punch is to be

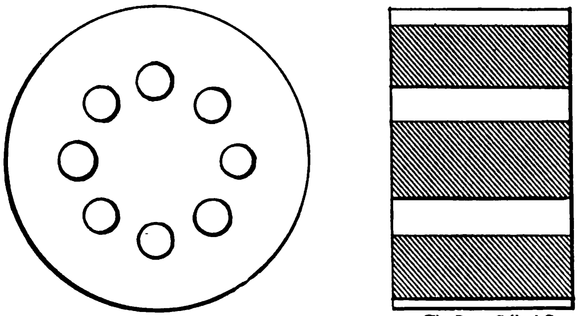


Figure 62. Heating block for tempering long, slender punches.

subjected to great pressure, it must be hardened the entire length, and the temper drawn equally the whole length. This can be accomplished by heating in a heating machine of the design shown in Fig. 48, or the punches may be placed in a pan containing sand and drawn over a fire. Or they may be placed in a kettle of hot oil, gauging the heat by means of a thermometer.

If intended for piercing a heavy, tough stock, they will be found to work very satisfactorily if drawn to a full straw color, 460°.

Many hardeners and others look askance at thermometers and always associate them with theory rather than practice, with the laboratory rather than

the workshop. In reality they are just as practical a tool as a steel scale or a micrometer, and, like them, enable us to measure rather than to guess.

Forming Dies.

When hardening forming dies or dies for compression work, if a great amount of pressure is to be exerted in order to perform the necessary work, the dies will not stand up as well if hardened at a low heat as though heated somewhat hotter. The outside surface will be hard, but under pressure this surface will be forced or crushed in, the interior not being hard enough to resist the pressure on the outer surface. It is, as stated, sometimes necessary in such cases, to heat the block somewhat hotter than if it were a cutting tool, yet care must be exercised that the piece be not overheated. But while it may be advisable to heat somewhat hotter than is the case with most tools, the heat ***must be uniform throughout*** the die.

It is not, generally speaking, advisable to draw the temper very much on tools of this description, but it is necessary to remove the tendency to crack from internal strains. This is done by heating the die over a fire until it is at a temperature that makes it impossible to hold the hand on it, yet not hot enough to perceptibly start the temper, or it may be boiled in a kettle of water for several hours.

Ring Dies.

When hardening large ring dies or pieces of a circular shape, whose size and weight make it impracti-

cable to harden by ordinary methods, it is a good plan to heat in a furnace made especially for this class of work. Such a furnace is seen in Fig. 63, which shows a circular block A in position for heating. It is resting on strips of iron C supported by pieces of fire-clay B. The circular piece being heated should be in the center of the furnace—*i. e.*, evenly distant from the inner walls. The cover D is attached to the mechanism for raising the cover, and held by the chains EE. It is possible, by using proper care, to heat work very uniformly in a furnace of this description.

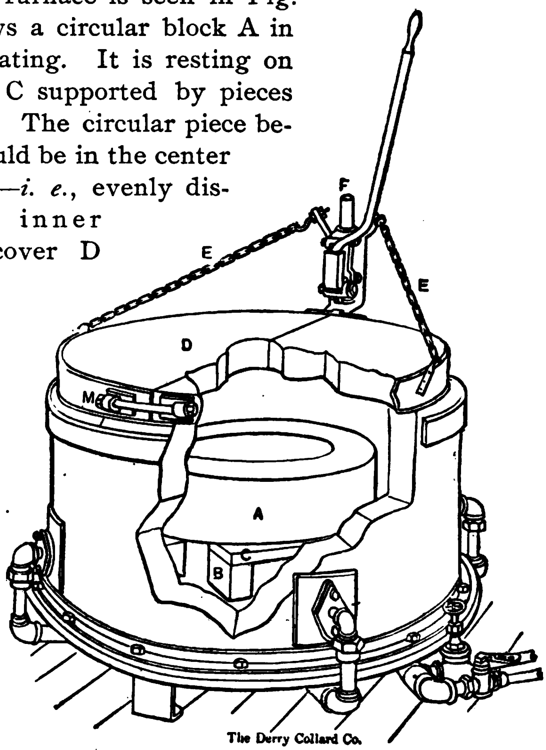


Figure 63. Gas furnace for ring dies and similar work.

A method the writer has used with excellent results when hardening work of this character, consists in placing the ring or circular die in an iron box two or three inches larger each way inside than the circular piece. A circular box gives better results than a square one, as

more uniform heats may be obtained. Place 1½ inches of a mixture of equal parts granulated charred leather and charcoal in the bottom of the box. Place the piece of work on this, cover with the mixture to a depth of an inch or so, put the cover on the box and place in the furnace.

When the piece is of a uniform red heat, the box may be removed from the furnace and the piece of work taken out by grasping it with tongs on opposite sides, as shown in Fig. 64. Place it on a device which consists of a ring having three handles, as represented in Fig. 65. Have the ring (which should be made of iron or machinery steel) considerably thinner than the thickness of the piece to be hardened, but wide enough to screw the handles in as shown. The handles *b b* are threaded on one end and bent; they are then screwed into the ring, as shown. A stud *c* having a tapped hole is screwed in also. The third handle is screwed into this. The object of making it by this method is, the handle may be unscrewed from the stud *c* and the piece to be hardened put in place. The handle may then be screwed into the hole in stud. If the piece of work is very large and heavy, a man may

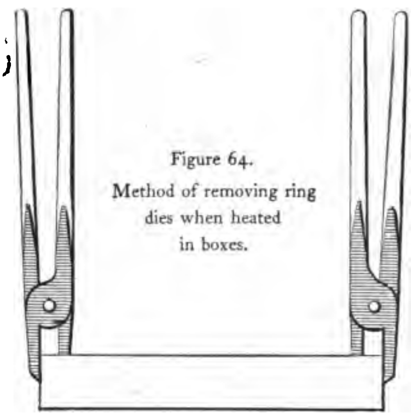


Figure 64.
Method of removing ring dies when heated in boxes.

be stationed at each handle. If not very heavy, two men can handle it all right. The operators should protect their hands and arms in some manner to prevent being burned by the steam generated when the red hot piece comes in contact with the water.

It will be necessary to use a bath having a jet of water coming up from the bottom, so as to cool quickly, when hardening work of this description. Before immersing, the water should be turned on, and at the minute the piece is dipped, a quantity of table salt (about a pint) should be thrown into the water. The ring should be worked up and down in the bath. When the "singing" ceases, the supply valve may be closed. The water in the bath may become somewhat warm, but it will reduce the liability of cracking. As soon as the piece of work is reduced to the temperature of the bath, it may be removed, placed over a fire and heated to prevent cracking from internal strains. If it is necessary to draw the temper, the piece of steel may be brightened while heating and the temper drawn at this time.

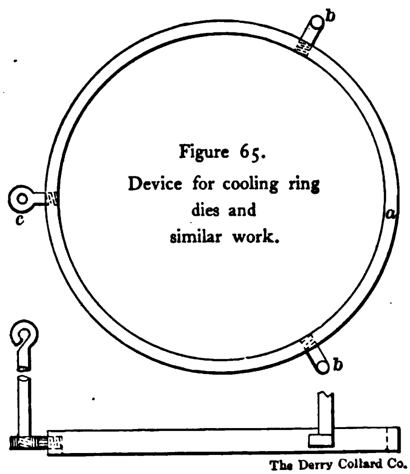


Figure 65.
Device for cooling ring dies and similar work.

It is advisable when drawing the temper of articles

of this description to ***heat very slowly***, so as to have all parts of an equal temperature. If possible, have the heat so uniform that it will not be necessary to quench the article when the desired heat is reached. Should the temper colors, however, run so fast that it seems necessary to quench in order to keep it from becoming too soft, it should be dipped in oil or *hot* water, as, if dipped in cold water, it would have a tendency to cause brittleness.

Screw Threading Dies.

There are several forms of the die under consideration. They are sometimes made square, then again they are made round in shape, with no means of adjustment. They are then termed solid dies. Most square dies are made solid.

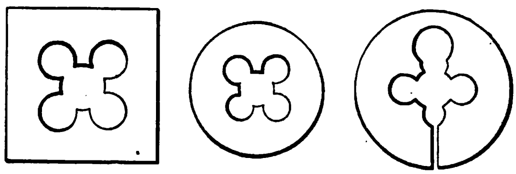


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Figure 66. Various styles of screw threading dies.

When it is necessary to cut a screw to size or to gauge, it is generally considered advisable to make the *finish* die of a form known as an adjustable die. The forms referred to are shown above, in Fig. 66.

The solid square die, being used mostly for threading bolts and similar work where accuracy is not essential, are usually made to cut *small* enough, and no particular pains taken when they are hardened. How-

ever, if a die of this form is hardened all over, the contraction from the outside edges is very unequal, on account of the corner containing more stock than the portion between. Owing to the unequal contraction, the cutting edges do not have an equal amount of work to do, so one cutting edge dulls more rapidly than the other. Every tool maker knows the secret of success in making a screw threading die that will work satisfactory, lays in having each cutting edge cut *its* proportional amount. It will readily be seen that any *unequal* contraction or wear, which causes an upsetting of this equality in cutting, must reduce the usefulness of the tool.

Too often no account is taken of the *amount* of work a tool will do after it is hardened. If it survives the ordeal of going through the fire and water, and will cut, it is considered a successful job of hardening.

From the preceding it will be seen that it is necessary, in order that best results may follow, that the die be in (as near as possible) the same shape, and the location of the cutting edges be the same as before hardening. Now, in order to accomplish this result, it is necessary to treat the die in a manner that will cause the cutting portion to harden *first*. By so doing, the contraction of the outer portion does not seriously affect the cut-

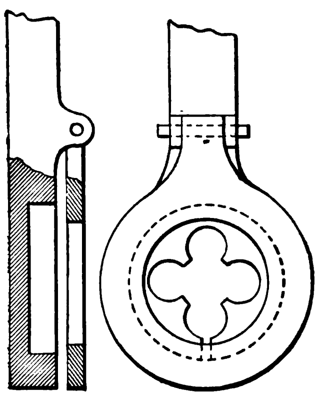


Figure 67. Device for cooling screw threading dies.

ting qualities of the tool. When hardening a square or a solid round die, it is sometimes considered advisable to place the die in a fixture, as shown in Fig. 67. It is then immersed in the bath and swung slowly back and forth in order that the liquid may readily pass through the opening, thus insuring the hardening of the cutting teeth. The portion near the circumference is, of course, soft. This is rather to be desired than otherwise in the form of die under consideration.

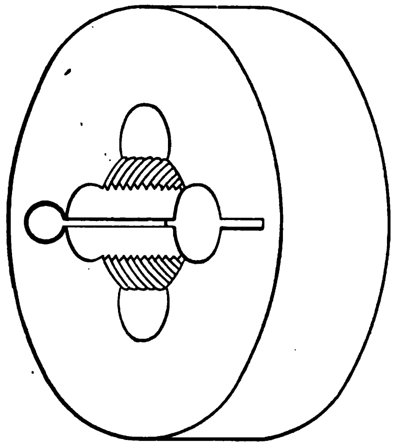


Figure 68. Method of preventing "twist" in screw threading dies.

When adjustable dies are hardened, it is generally considered necessary to harden the outer portion in order to furnish a certain amount of elasticity, in order that the die may open uniformly when expanded. The necessity of this depends on the design of the die. If stock enough is left at the portion where the die is supposed to spring, the stiffness of the stock will give it sufficient tension. Should it be necessary to harden the outer portion somewhat, the fixture may be cut away in a manner

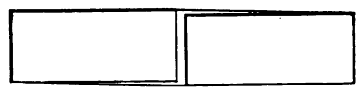


Figure 69. Example of "twist" in screw die.

that allows the contents of the bath to come in contact with the steel nearer the outer edge.

Adjustable dies of the description shown should not be cut entirely through at the point where pressure is applied to open them, but may be cut nearly through,

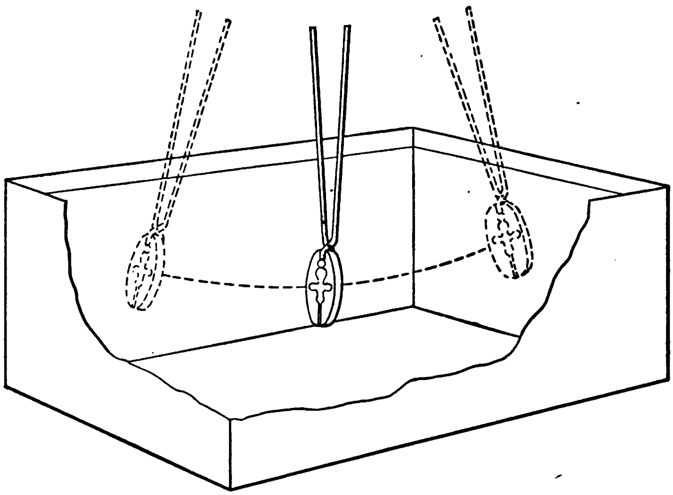


Figure 70. Method of cooling dies for thread cutting.

commencing at the inside and cutting toward the outside, leaving a thin partition, as shown in Fig. 68. This partition holds the die in shape, preventing the tendency to twist, shown in Fig. 69.

When it is not considered advisable to make or use a fixture as described, the die may be grasped, after being heated, with a pair of tongs, as shown in Fig. 70, and quenched in a bath of lukewarm water or brine, swinging it slowly back and forth, as represented. When hardening any tool of this description,

bear in mind the fact that the article should never be heated in a manner that allows the cutting teeth to become oxidized by exposure to the air while heating. Best results are obtained by heating in a muffle or a piece of pipe. If the surface of the teeth become covered with a scale of oxide, this raises, and keeps the contents of the bath from acting, thus causing soft spots, which render the tool practically useless.

An excellent plan consists in heating the dies in an iron box having a half inch of charred leather in the bottom. Fill the opening in the die with the same material. When the die reaches a uniform temperature which is right to produce the desired result, quench in the bath.

When hardening "spring" dies, or, as they are familiarly termed in some shops, "hollow mill dies," best results are obtained by dipping in the bath with the cutting end uppermost, as described under Hardening Hollow Mills.

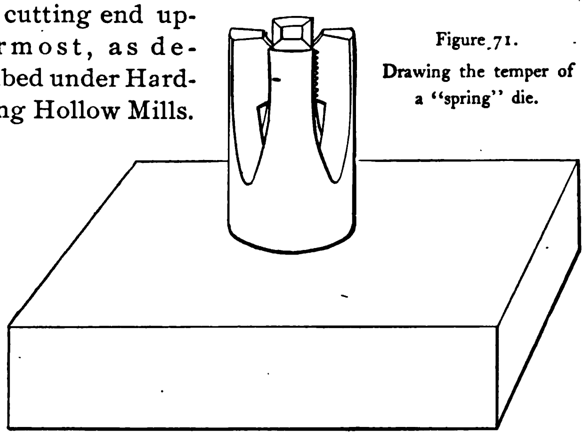


Figure 71.
Drawing the temper of a "spring" die.

Generally speaking, it is not necessary to heat the die much beyond the length of the threads.

Tempering small dies.

The temper may be drawn by placing the die on a hot plate, as shown in Fig. 71, drawing from the back end. On account of the shape of the cutting edge, which makes it stronger than the ordinary form of screw threading die, it is not necessary to draw the temper as much. A faint straw color making them about right, unless the cutting tooth is long and weak, in which case it may be drawn to a full straw color.

If many dies are to be tempered at a time, the cost may be reduced very materially by heating in a kettle of oil, drawing them to a temperature which varies from 460° to 500°, according to the conditions previously mentioned.

When but one or two are to be done, it is advisable to brighten the sides and draw the temper by laying them on a flat plate, moving around on the plate, and turning them over occasionally. The temper color should be from a straw to a brown color. If it is considered advisable to draw the temper of a large batch of dies by the hot plate method, the plate may be placed over a fire, in order to maintain a uniform heat. Quite a number of dies may be placed on the plate at a time. It is necessary to turn them occasionally, as mentioned. As one shows the proper temper color, it may be removed and placed in a dish of *warm* oil. By this method a skillful operator can temper a large batch of dies in a comparatively short space of time, but the results will not be as satisfactory as though heated in oil.

The amount of work to be done will always determine the most economical method of doing it, but it is better to err on the side of having too many conveniences. A few spoiled tools will pay for several improvements.

Cracking of dies from internal strains.

Large pieces of steel are more liable to crack as a result of internal strains than smaller pieces. On account of the weight of the piece there is a tendency on the part of some hardeners to neglect reheating the piece to overcome this tendency to crack, due to various uneven heats the steel may have received.

In order to overcome this tendency, the die should be reheated in a uniform manner to a temperature that allows the various portions to conform to any strains in the piece. This may be accomplished by placing the die in the fire, turning it occasionally, in order that it may be uniformly heated, and heating until moisture applied to the surface forms steam. This method when applied to *large* pieces is not apt to result in the center of the piece being heated as hot as the outside. Consequently *better* results will follow if the die is placed in a kettle or tank of boiling water (212°) and left there until heated uniformly throughout. If the die is large this will necessitate leaving it in the water at the boiling point for several hours, as it takes longer to heat a large piece of steel throughly than we realize. It pays to be very careful about these little points, as these dies are often expensive.

Hardening Long Articles.

Most hardeners dread hardening long, slender articles, on account of the uncertainty attending the operation, so far as results are concerned. If the article is a reamer or similar tool, having teeth on the outer surface, it will not require as great an amount of heat as though it were a solid piece. In any case, however, do not heat any hotter than is necessary to

accomplish the desired result, always remembering that *even* heats are the *secret* of success when heating steel for hardening. If the tools are hotter on one side than the other, unequal contraction must take place; consequently, the article will be crooked.

When hardening long reamers and similar tools, it is *necessary* that the heat should be *uniform* and as *low* as possible. It must be the same on each side. If one side be a low red and the opposite side a bright red, and it is quenched in the bath, it is sure to come out crooked. A piece of this description must be dipped in the bath in as nearly a vertical position as possible, as shown in Fig. 72, in order to cool both sides uniformly. If it be dipped at very much of an angle, as shown in example marked "wrong," it will surely spring, on account of the uneven contraction of the two opposite sides. It is necessary to work such pieces up and down in the bath, changing the location occasionally in order to avoid the effects of the steam generated.

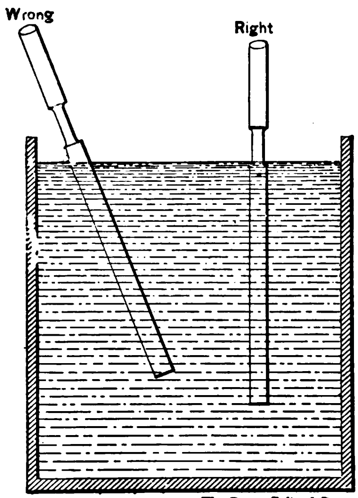


Figure 72. Proper method for dipping long articles.

These may seem like unnecessary precautions, but the results obtained will show that it is worth while

observing them as thoroughly as possible. It's the little things that count in successful hardening and tempering.

Condition of the Bath.

If the tool is of a design that makes springing a possibility when the article is quenched, it will be necessary to warm the contents of the bath considerably, the degree to which it should be heated depending on the shape of the tool and the temper of the steel used. Excellent results are many times obtained with a bath heated to a temperature of 100° to 150°.

The writer has had excellent results when hardening articles of this description by placing them in tubes one inch larger inside than the piece to be hardened. It should be placed in the center of the tube, the space between the article and the tube being filled with charred leather. The ends should be stopped and sealed with fire-clay. The tube is then placed in the fire and given a uniform heat for a period that insures the article being evenly heated to the desired temperature, when it may be removed from the tube and plunged in a warm bath of brine or the citric acid solution.

Hardening Taps.

It is necessary to take into consideration the design of the tool, the steel used, and the nature of the work to be done by the tap. If the tool is very long and it is necessary to harden but a small portion of the length, it is not necessary to heat it any farther up than the

length which requires hardening. In such cases it is a comparatively simple job.

When a long tap requires heating and hardening its *entire* length, it is necessary to devise some way of uniformly heating the piece. It is also necessary to quench in such a manner that all portions will cool as uniformly as possible, to avoid unequal contraction, thus preventing springing or cracking.

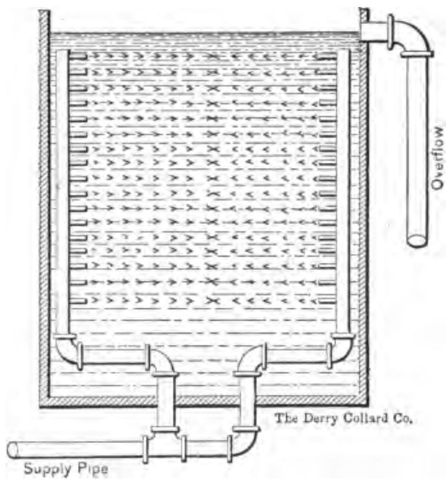


Figure 73. Bath for hardening taps.

When hardening taps, care should be exercised that the teeth are heated no hotter than the refining heat, or they will be brittle. If heated hotter than necessary, it must have the temper drawn very low, or the teeth will snap off when used. If the temper is drawn low, as described, the tap is too soft to perform its full share of work. When hardening tools having teeth or projections, it is essential that the heat be the lowest possible. It is advisable to heat in a muffle furnace or enclosed in some receptacle to remove it from the products of combustion in the furnace and from oxidation by the action of the air. When it

reaches a low, uniform heat, dip in the bath of water or brine, preferably the latter. Work up and down rapidly, to bring the contents of the bath in contact with the teeth; or, better still, use a bath as shown in Fig. 73, having inlet pipes on opposite sides of the tank, these pipes being perforated, as shown. It is advisable to have the piping so designed that the upright perforated pipes may be placed against the side of the tank or moved toward each other, in order that the jets coming out of the holes may strike the object with sufficient force to drive the steam away, thus allowing the liquid to act on the steel.

Long taps give best results if packed in a tube with carbon, in the form of charred leather, as described in hardening reamers. When it has reached the proper uniform hardening heat, it may be hardened by immersing in the form of bath represented in Fig. 73. If a bath of this description is not at hand, very satisfactory results may be obtained by dipping in an ordinary bath of the desired temperature, and revolve the piece rapidly in the bath to insure uniform results. This will in a measure imitate the bath mentioned.

A bath of brine, or the citric acid solution, give excellent satisfaction for hardening tools of this description. Unless the tap is of large diameter, do not use a cold bath.

Hardening Small Taps, Reamers, Counterbores, Etc.

When small articles of this description are hardened in great quantities, it is necessary to devise means

whereby they may be hardened cheaply, yet the work must be done in a satisfactory manner. Various methods are employed to accomplish this, and one of the most successful methods that has come to the writer's attention consists of a furnace made with a

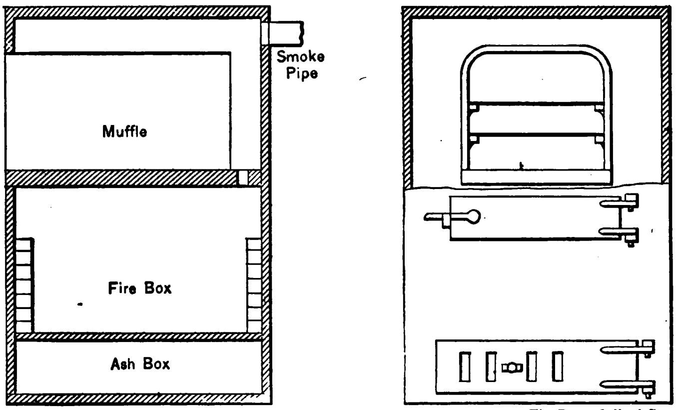


Figure 74. Muffle furnace for heating taps.

muffle. The heat was furnished by burning illuminating gas, or it may be designed to burn coal. The muffle was made as shown in Fig. 74. Cleats are cast on to the walls of the muffle, which in this case was cast iron. On these cleats shelves were placed, and on these shelves the pieces to be hardened were heated. It was necessary to turn the pieces over occasionally to insure uniform results.

When a piece was heated to the proper temperature, it was taken by means of a pair of tongs and dropped into a bath, which consisted of a tank having

several tube-shaped pieces of wire netting, as shown in Fig. 75. The tubes were slightly larger inside than the diameter of the largest part of the tool being hardened. Tubes of various sizes were used, the size depending on the diameter of the tools to be hardened. The tank had a supply pipe coming up

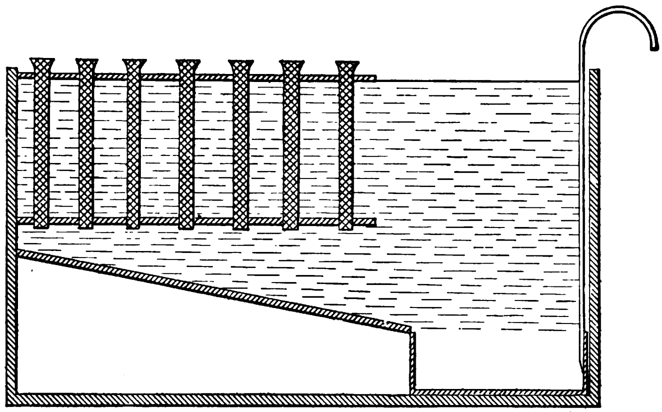
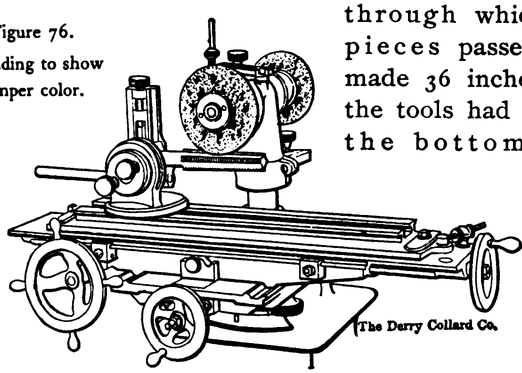


Figure 75. Bath for hardening taps and reamers.

from the bottom. This was connected with a supply tank overhead. A pump was used to force the water into the supply tank. It was possible to use a bath of clear water, brine, or any favorite hardening solution. In this case, the bath consisted of the citric acid solution, described under "Hardening Baths." It was kept at a temperature of about 60°. As fast as the pieces were heated to the desired temperature, they were taken with tongs and dropped into one of the tubes, the cutting end being down. They

passed down through the tubes on to an incline, and then into a catch pan, as shown. The distance the pieces traveled in the bath was considered when designing it. It was found by experiment that the largest piece to be hardened would cool below a red heat in falling a distance of two feet in the bath. To make satisfactory results a certainty, the depth of the part of the tank through which the pieces passed was made 36 inches. If the tools had struck the bottom and

Figure 76.
Grinding to show temper color.



turned on their side before the red had disappeared from the surface, they would have, in all probability, sprung; but, as it was, excellent results were obtained.

When taps are brightened, in order that the temper colors may be visible, it is not advisable to use a piece of emery cloth on a stick or round file, as is often done, because unless the operator is *extremely* careful, he is apt to cut away the cutting edge of the teeth, thus rendering the tool unfit for use. If possible, use an emery wheel of the shape of the groove, as shown in Fig. 76. It is not absolutely necessary to use a fixture, as the tap may be held in the hands for brightening.

In this way, not only is the steel brightened, so the colors may be readily seen, but the cutting edges are ground sharp, and any burrs thrown up between the teeth are ground away.

When but a few taps are to be tempered, it is possible to heat them sufficiently in a gas jet or the flame of a Bunsen burner; sometimes the flame of a candle is used when the article is very small, as in Fig. 77. With a blowpipe, a hot flame can be produced.

When the taps are made in quantities sufficiently large, it is much more economical to draw the temper by placing in a kettle of oil, gauging the temperature with a thermometer.

The amount necessary to draw the temper of a tap in order to get desired results, depends, as with most other cutting tools, on the steel used, the heat given when hardening, and the use to which they are to be put. Very small taps that are to be used by hand may be left harder than those intended for use in a screw machine. Taps used by hand should be drawn to deep straw or brown color, while those used on screw machine work need drawing to a deep brown, and in some cases to a purple.

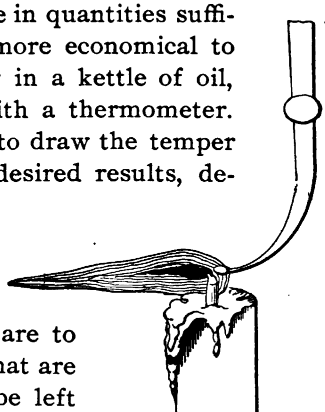


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Figure 77. One way to heat small taps.

Half Round Reamers.

These should be heated very carefully in a pipe or muffle furnace to the lowest heat possible to harden.

Method for cooling half-round reamers.

When dipping in the bath, the reamer should be inclined somewhat from a perpendicular position, the heavier portion being on the lower side, as shown in Fig. 78, to avoid a tendency to spring. The contents of the bath should be heated as warm as is consistent with good results, as this will help keep it straight.

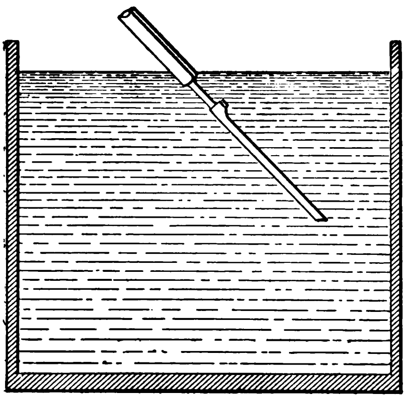

Figure 78. Proper method for cooling half-round reamers.

Should the reamer spring somewhat in hardening, it may be straightened by reheating and exerting a pressure on the convex side.

If the projection has been left on the end, as shown in Fig. 79, the reamer may be placed between centers and straightened, as represented elsewhere.

Should it be a reamer having *no* center at the small end, it may be placed on two V blocks, as shown in Fig. 80. Apply heat by means of a gas jet, spirit lamp, or any other means to the lower side, heat until oil placed on the surface commences to smoke. Now apply pressure at P, on top side. When it has been sprung the proper amount, cool by means of wet waste.

The possibility of straightening reamers and similar work means such a saving in many shops that it

will pay to have special attention paid to it, as crooked tools of any kind cannot do accurate work. It will pay to rig up fixtures especially for this, as the saving is far greater than the cost.

Small, half-round reamers should be drawn to a full straw, or a brown color for most work.

Hardening Milling Machine Cutters.

As most shops have at least one milling machine, and many shops hundreds, there are probably more cutters hardened for this class of work than for any other.

In hardening this class of tools, it is necessary to

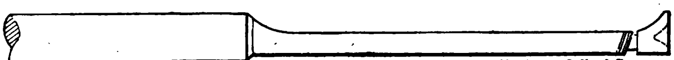

Figure 79. Half-round reamer.

have them hard enough to cut the metal being machined, yet tough enough to stand up under the strain to which it must be subjected.

Milling machine cutters should be hardened at a lower heat than a solid piece of the same size. The teeth, being slender and projecting from the solid body, take heat very readily. When possible, tools of this description should be annealed after a hole somewhat smaller than the finished size has been drilled and the tool blocked out to shape in order to overcome the tendency to crack from internal strains. If it has not been possible to do this, or if for any reason it has

not been considered advisable, the cutter may be heated to a low red and laid to one side and allowed to cool until the red has disappeared, when it may be reheated and quenched. It is always better, however, to anneal after blocking out if it can be planned so as to take the time necessary to do this. The results are more satisfactory in every way.

It may be well to again caution the reader in regard to the heats. The teeth of this form of tool being thin, are apt to absorb heat faster than one realizes, and as a consequence, they become too hot. If a cutter is

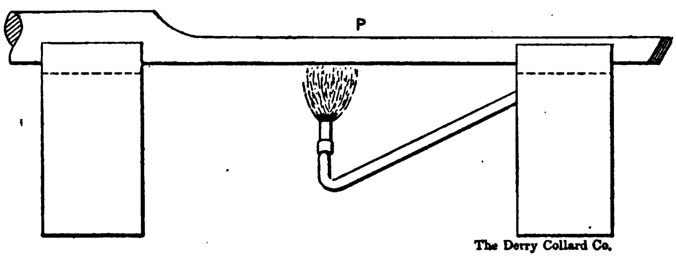

Figure 80. Straightening a half-round reamer.

overheated, it will not do as much nor as satisfactory work as though properly heated; but should the teeth by any carelessness become overheated, do not quench at that heat, thinking no one will know the difference. While it is possible to misrepresent the condition of the heat when describing it, the texture of the steel always tells the truth in regard to what the operator has done with it when in the fire. Neither is it a good plan to hold it in the air and let it cool until the color shows about right, because it is hotter inside than on the outside; and then again, the grain will be as coarse

as though it were dipped at the higher heat. It should be allowed to cool off and then heated to the refining heat and quenched.

When this form of tool is ready to harden, place it on a wire, bent as shown in Fig. 81. The wire should be large enough to hold the cutter without bending, but not much larger, as it should not impede the circulation of the fluid through the hole of the cutter. Neither should any considerable sized piece of steel rest against the side of the cutter, as the action of the bath would not be uniform if it were kept away from some portions of the piece. The cutter should be worked around well in the bath until the teeth are hard, when it may be removed and plunged in oil and left until cold. It should then be taken and held over a fire and heated sufficiently to remove any tendency to crack from internal strains. The temper may now be drawn the required amount.

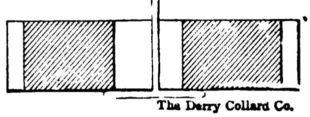

Figure 81. Proper way to cool milling cutters.

A method in use in many shops, consists in dipping the cutter in a bath of water having one or two inches of oil on the surface. The cutter is passed down through the oil into the water. Fig. 82 shows a bath of this description. The oil does away with the first sudden shock, which results when hot steel is plunged into cold water, and as a small portion of the oil adheres to the teeth, especially in the corners where the teeth join the body of the material,

the action of the water is not as "rank" as would otherwise be the case. Where the teeth are long or the mill is of irregular contour, it is advisable to heat the water somewhat. Water or brine, heated lukewarm, works fully as well as though cold on tools of this description and is not as likely to crack them. When the outline is very irregular and the tool is made of high carbon steel, the writer has had excellent success using a bath of brine heated to 80° Fahr. The idea that a bath must be as cold as possible has probably ruined more steel than we realize.

Drawing Temper of Milling Machine Cutters.

A method in very general use for drawing temper of milling machine cutters, consists in placing the hardened cutter on an iron plug of the form shown in Fig. 83, the plug having been previously heated sufficiently to draw the temper of the cutter.

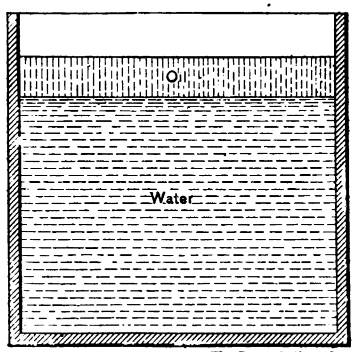

Figure 82. Oil and water bath for milling cutters.

The plug, when heated, should not fill the hole in the cutter. In order to heat the cutter uniformly, it should be turned constantly on the plug.

It is, of course, necessary to brighten the backs

of the cutter teeth in order that the temper colors may be readily discerned.

The writer has had best results by holding the cutter over a fire, or a hot plate, and warming the circumference to a degree that made it impossible to

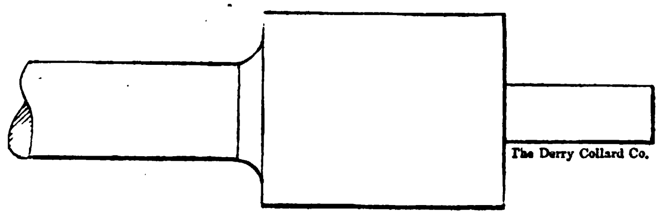

Figure 83. Plug for heating milling cutters.

hold the hand on it, previous to placing the cutter on the plug. It was then placed on the plug and turned constantly until the proper temper colors showed, when it was plunged in oil to prevent its getting too soft.

The object attained in heating the outer surface first, was that the heat given was sufficient to make the steel at this point somewhat pliable; whereas, if the cutter had been placed when cold on the red hot plug, the cutter absorbing the heat would tend to expand the steel toward the outer, rigid surface. If this expansion should prove, as it does many times, to be greater than the steel could stand, cracks would result.

The amount of heat necessary to give a milling machine cutter when drawing temper can not be stated arbitrarily. It is desirable to leave it as hard as possi-

ble, and yet not have it too brittle to stand up when in use; consequently, it should not be heated any hotter than necessary when hardening. It should *not* be plunged in a bath of extremely cold fluid, neither should it be checked in cold water when the temper has been drawn sufficiently.

While it is not considered advisable by many mechanics to make cutters of this description of a *high* carbon steel, the writer's experience has convinced him that better results are obtained by using a high carbon steel extremely *low* in phosphorus, and using *extreme* care in the heating. Then quenching in a bath of warm brine, 80° to 100° Fahr.

For ordinary work, a faint straw color (430°) gives best results, although it may be necessary at times to draw to a full straw color, 460°.

A kettle of oil, heated to the desired temperature, furnishes an ideal method of tempering cutters of this description. This method has been fully described under the proper section on pages 121 and 122, and should be carefully considered in connection with tools of this character

Hardening Shank Mills.

The percentage of carbon necessary to give the best results, depends on the make of steel. For ordinary work, however, a steel having 1¼ per cent. gives good results.

The methods employed in heating and quenching shank mills when hardening, depend in a measure on the form of the mill and the custom in the individual shop. Mills of the form shown in Fig. 84, may be

heated to a uniform low red heat for a short distance above the teeth, stopping the heat in the necked portion, marked *a*. In some shops it is the custom to leave the shank quite a little larger than finish size in order that it may be turned to size in the lathe and fitted to

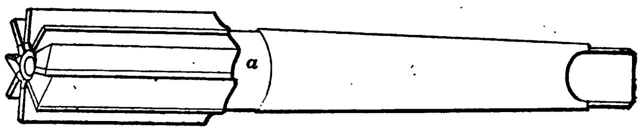

Figure 84. How to harden shank mills

the collet or spindle after hardening. In such cases it is necessary to leave the shank soft its entire length. In other shops it is the custom to turn the shank nearly to size before hardening, leaving on just enough to allow for grinding to a fit and remove any untruth resulting from springing in hardening. If it is necessary to leave the shank soft its entire length, care should be exercised in heating and dipping in the bath that the shank is not hardened in the least. If it is to be ground to a fit, the same care is not necessary, although greater care must be exercised in grinding if the shank is hard for a short distance and the balance is soft; but if careful when taking the finishing cuts on the grinder, no trouble need be experienced. If the cutter is made as represented in Fig. 85, it will be necessary, in order to harden the teeth the entire length in a satisfactory manner, to harden the shank for a short distance.

When hardening a cutter of the description shown

in Fig. 86, having a recess of considerable depth in the end, much better results will be obtained if it is dipped in the bath with the hole uppermost, as shown in Fig. 87—that is, provided it is necessary to harden the walls of the hole. If this were not desirable, then it would be safest to fill the hole with fire-clay, mixed with water, to the consistency of dough, and the cutter dipped as shown on next page. If the hole was not filled and the cutter was dipped in the bath with the hole down, the steam generated would drive the water away from the teeth at end; and furthermore, the steam would very likely cause the thin walls to crack.

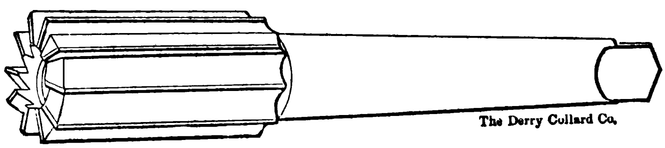

Figure 85

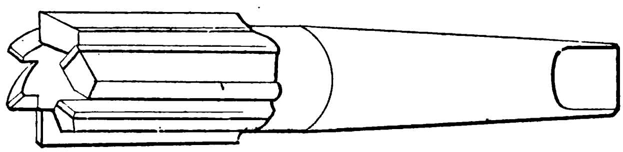

Figure 86. Shank mills.

When hardening cutters of the form shown in Fig. 88, known as T slot cutters, it is necessary to harden the entire length of portion necked below size of shank for several reasons. When the neck portion is slender, this is necessary, in order to strengthen this

portion so it will not spring or twist off when the cutter is in operation. If the cutter is of a size that makes the necked portion large and strong enough to resist the cutting strain, it might not appear at first thought necessary to harden this. But as it is generally made but a few thousandths of an inch smaller than the slot it travels in, it will, if left soft, become roughed up by the fine cast iron chips, which are liable to get between the walls of the slot and the stem. Consequently, it will be readily seen that in most cases it is advisable to harden the entire length of the necked portion.

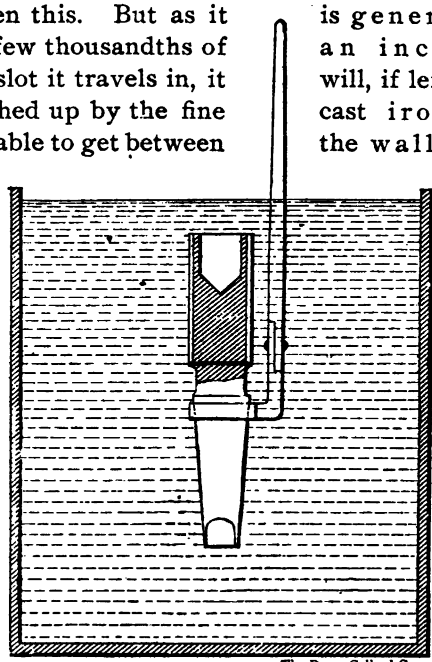

Figure 87. Proper method for treating shank mills.

If there is considerable difference between the size of the cutting portion and the shank of the tool, the cutter should be made, if possible, with a fillet in the corner, as shown at *a*, in sectional view of Fig. 89. If, however, this precaution has not been taken, or it has not been possible to do it, a piece of iron wire may be wound around, as shown at *b*. This wire being red-hot when the cutter is dipped in the bath, has the effect

of keeping the contents of the bath away from the sharp corner until the larger and smaller portions of the mill have become hardened to a degree, thus reducing the liability of cracking at this point. When the cutter has been heated to a low red, it should be plunged into a bath of water or brine from which the chill has been removed; work around well in the bath until it is of the same temperature as the bath, when it may be removed and the temper drawn.

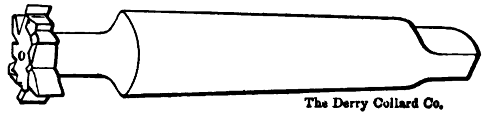

Figure 88. T slot cutter.

If it has not been possible to heat the cutter in a muffle or in a piece of pipe or other receptacle, it will be found an excellent plan to have a strong solution of potash and water, which should be heated quite warm. Before the cutter is heated, it may be plunged into the potash solution. Place it in the fire and heat to the proper hardening temperature and plunge in the hardening bath. The effect of the potash is to cause any thin scale of oxide which may have formed on the surface to drop off the instant the tool touches the bath. If this scale adheres to the piece, it has a tendency to rise in the form of a blister when in contact with a cool liquid, and consequently it keeps the contents of the bath from acting on the steel directly underneath.

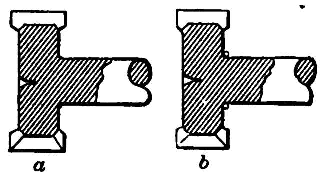

Figure 89. Fillets for T slot cutters.

Drawing temper of T slot cutters.

When drawing the temper of a tool of this description it is necessary, in order that the necked portion be as strong as possible (especially if it is slender), to draw it to a purple or even a blue color, while the cutting teeth need drawing to a straw color.

It is surprising to one not thoroughly posted in the effects of different degrees of heat on steel to find how hard a cutter of this kind may be left if it was properly heated when hardened. This is best seen by comparing with one that was heated a trifle too hot, yet not to a degree that is generally considered harmful to the steel. In the case of the cutter properly heated—that is, to the refining heat—it may be left when tempering at a faint straw color, while if given a trifle more heat, it is necessary to draw it to a full straw, a difference of 30° of heat, and a vast difference in the amount of work it will do between grindings. In order to successfully draw the temper, the necked portion may be placed in the flame of a gas jet, a Bunsen burner, the flame of a spirit lamp; or, if none of these are available, and it is necessary to use a blacksmith's forge for all work of this description, a piece of sheet iron having a hole in it may be placed over the fire. A jet of flame will come through the hole, which may be made to strike the necked portion. In this way the desired temper may be obtained.

Hollow Mills.

When articles having a hole running part way through them, as, for instance, the hollow mill shown in Fig. 90, are to be hardened, it is advisable to dip

them in the bath, with the opening uppermost, as represented in Fig. 91. If the mill were dipped with the opening down, it would be almost impossible to get water to enter the hole for any considerable distance,

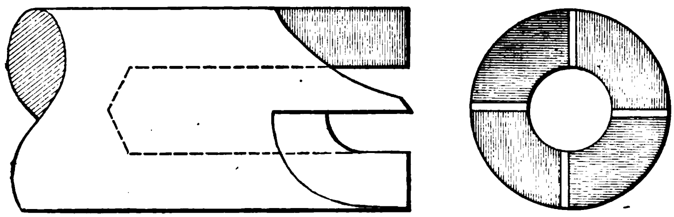

Figure 90. A hollow mill.

as the steam generated would blow the water out. As a consequence, the walls of the hole would not harden, and the steam would in all probability cause the steel to crack.

Then again, best results will follow if the frail end is not chilled until after the heavier, solid portions have contracted somewhat. If the lighter portions are chilled and contracted before the heavier ones, the tendency is for the heavier parts, which are stronger than the lighter, to pull them into conformity with themselves, and as the steel is hard and rigid, it must crack. While this principle is explained elsewhere in this work, it seems wise to show the adaptability of this peculiarity of steel to pieces of this description.

When making articles having holes, as shown, if the piece is to be hardened, the liability of cracking will be lessened if the stock at the end of hole is left, as shown in Fig. 92. If, however, the piece is made

with a sharp corner, as shown in Fig. 93, it is advisable to fill in this sharp corner with fire clay, or graphite, in order that there may be no pronounced difference in the contraction of the two portions.

When hardening pieces of this character, it is, generally speaking, good practice to use a bath of tepid water or brine.

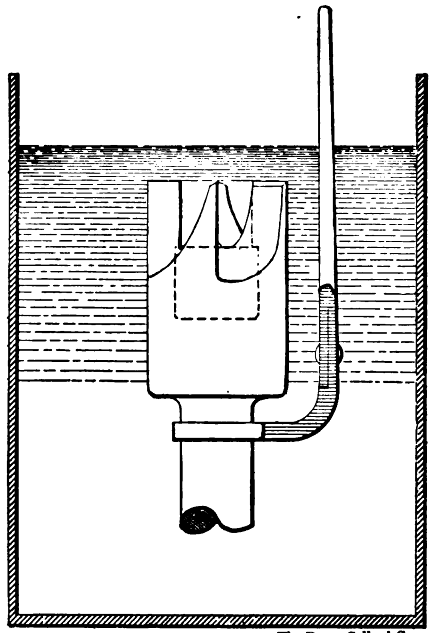

Figure 91. Method for hardening hollow mills

When it is considered desirable to harden a piece a certain distance, and no farther, and the facilities for heating do not allow of heating exactly the right distance, it is necessary to dip in the bath with the teeth down. In order to overcome the tendency of the steam to blow the water from the hole, a small vent hole is drilled through the wall of the piece, as shown in Fig. 94. If this hole is large enough to allow the steam to escape, good results will follow if a bath is used having a jet of water coming up from the bottom, as, by this means, water is

forced into the hole. However, the operator should bear in mind that it is never good practice to have

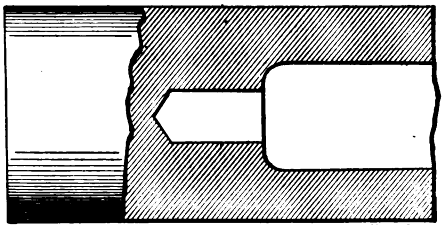

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Figure 92.
Hollow mill with rounded corners.

the hardening stop at a shoulder, either inside or outside of a piece of steel. Where possible, stop the

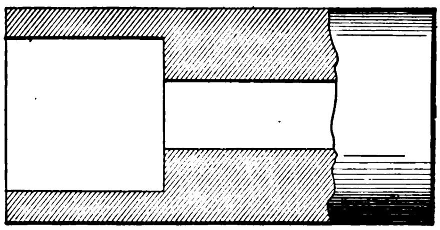

Figure 93.
Hollow mill with sharp corners.

hardening somewhat short of the shoulder, but if this does not meet the requirements, harden a trifle

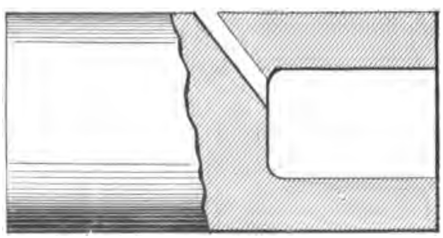

Figure 94.
Hollow mill with hole to allow escape of steam.

beyond the shoulder. This may seem like a little thing to bother about, but it generally means the difference between a good job and a poor one, and it's

one of the little points that count in making a successful hardener.

Thin Articles.

Thin articles, as screw slotting saws, metal slitting saws, etc., may be hardened between two plates whose faces are covered or rubbed with oil. If reasonable care is exercised in the operation, they will be very straight.

It is essential, in order to get good results, to heat the pieces on a flat plate. They should be heated no hotter than is necessary to accomplish the desired result. When at the proper heat, the saw may be taken by a pair of tongs, of the form shown in Fig. 95, and placed on a plate whose face is covered with lard, sperm or raw linseed oil. The advantage derived from using tongs of this description is, the saw is held by the portion near the hole, rather than by the teeth, as would be the case if a pair of the ordinary style were used. In that case, the teeth grasped by the tongs would not be of the same temperature as the balance of the saw; and, as a consequence, the hardening would not be uniform. Another plate, whose face has been treated in a similar manner, may be placed on top of the saw and held there until the saw is cold. It is necessary to

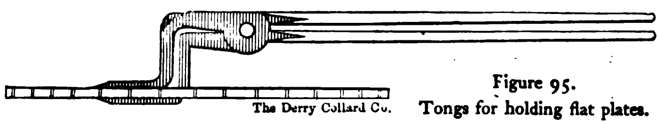

Figure 95.
Tongs for holding flat plates.

place the top plate in position as quickly as possible, after the saw has been placed on the lower plate.

If the saw should become chilled before the upper

plate is placed on it, it will spring somewhat, and the upper plate cannot straighten it. Should it be sprung

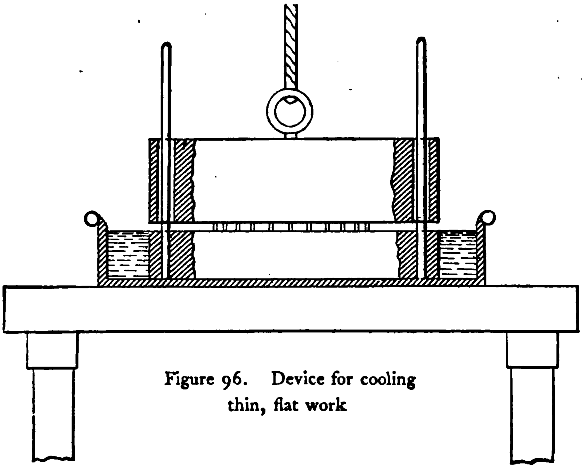

Figure 96. Device for cooling thin, flat work

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very much, the pressure applied to the upper plate will, in all probability, break the saw, as it would be hard and unyielding.

If many pieces of the description mentioned are to be hardened, it is advisable, for the sake of economy, to make a special device for chilling the work, as when two plates are used, it is necessary to have the services of two men, one to handle the saws, and one to work the movable plate. If the number of pieces to be hardened does not warrant an expensive apparatus, two flat plates may be used, drilling two holes in each plate, as shown in Fig. 96. The holes in the lower plate should be a driving size for ½ inch wire, while those in the upper plate should be $\frac{1}{16}$ inch larger than

the size of the wires. A cord should be attached to the upper plate, as shown. This cord should pass over a pulley and return to a treadle. The operator,

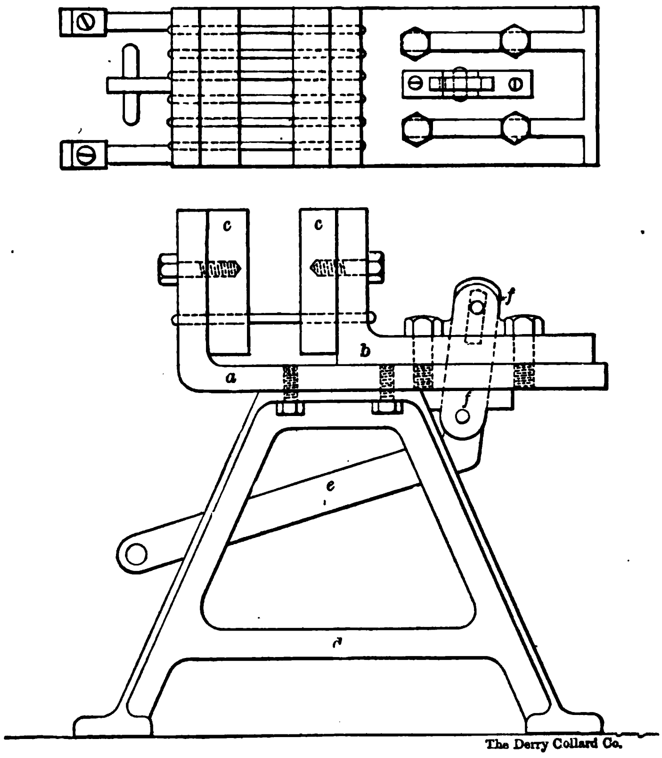


Figure 97. Device for hardening between plates.

by using this device, can handle the saws and operate the plate very nicely.

In Fig. 97 a device is shown for hardening thin pieces between plates, which consists of the base *a*,

and slide *b*, to which are attached jaws *cc*. Through the jaws are several wires for the work to rest on when it is placed between the jaws. The side is operated by the treadle *e*, which is connected to the base and slide by the brackets *ff*. The device is supported by the legs as shown. The advantage derived from using a fixture having the jaws standing in a vertical line, as shown, is, the piece of work is not as liable to chill while closing the jaws, as would be the case were the jaws in a horizontal position.

If the work is hardened in large quantities and the jaws show a tendency to get hot, they may be cast hollow and a water pipe connected with each, providing an outlet on the opposite side. In this way a circulation of water may be kept up through the jaws, thus keeping them cool at all times. In order to insure a

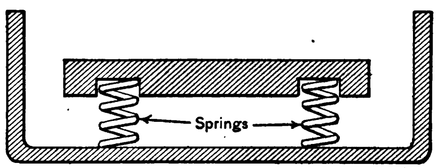


Figure 98. Cooling plate mounted on springs.

uniform circulation of the water, it will be necessary to have the inlet pipe at the lower edge, on one end of the jaw, and the outlet pipe on the upper edge at opposite end. The outlet pipe should be carried far enough to do away with any liability of any of the water getting on the surfaces of the jaws that were to come in contact with the pieces being hardened.

Cooling gun springs.

When saws or other pieces of considerable thickness are hardened between plates, it is sometimes necessary to provide for a supply of oil around the teeth when the plates are in position. In order to do this, it is necessary to use plates in a horizontal position, as shown in Fig. 98, having the lower plate resting on springs, or other arrangement to keep its upper face above the surface of the oil in the pan, until the work has been placed on it. The pressure applied by the upper plate must

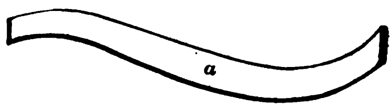


Figure 99. Gun spring.

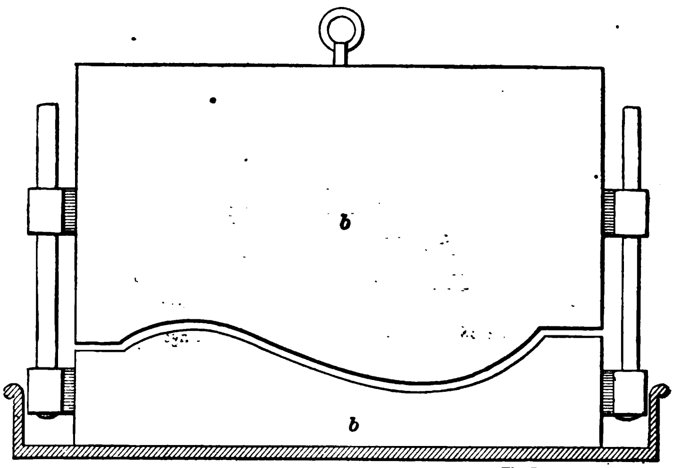


Figure 100. Method for cooling gun spring shown above or other irregular pieces.

submerge them in the cil in pan to a depth that insures the teeth being well covered with oil.

Drawing temper of slitting saws.

When drawing the temper of tools of this description best results can be obtained by putting the pieces in a kettle of oil, gauging the heat by a thermometer. While the degree of heat necessary to produce the desired result can not be given arbitrarily, as very much depends on the steel used, the amount of heat given when hardening, and the use to which it is to be put. But ordinarily, metal slitting saws for general jobbing purposes should be drawn to 460 degrees. Screw slotting saws, $\frac{1}{16}$ inch thick and under, 525 degrees. If thicker, do not draw as low.

The method of hardening between plates may be applied to pieces having other than flat forms. Take, for instance, springs which, in order to maintain a given tension, must be of a certain shape; for example, the main spring of a gun, as represented in Fig. 99. The form of spring is shown at *a*, while *bb* is a pair of plates, having their faces formed to harden the spring and keep it in the proper shape. It is not generally desirable or advisable to use a form when hardening springs of this character, but is sometimes necessary. The method and amount necessary to draw the temper of springs is given under Spring Tempering, and to avoid repetition the reader is referred to that section. It has seemed necessary to repeat some statements in order to show their different applications and to impress them on the mind.

Screw-Drivers.

There is probably no one article so generally used as the screw-driver that gives so much trouble. In the first place, not more than one man in ten understands how to properly make the tool, and then but a small

percentage of this one-tenth can harden and temper it properly after it is made.

A screw-driver is better for having been forged to shape, provided it is forged properly; that is, heated properly and hammered in a scientific manner. Unless one understands these operations well enough to do a *good* job, it is advisable to file or machine one from the bar.

A screw-driver should be made with the end that enters the screw slot of an equal thickness throughout, and to nearly fill the slot. At times, this precaution is observed, and the portion immediately adjoining is made much heavier and with square corners, as shown at *a*, Fig. 101. Now, on account of the unequality of size of the adjoining portions, it is a difficult matter to harden and temper it uniformly throughout. Then again, the shape is such that it must break where the heavy and light portions adjoin, on account of the unequal strength of the two portions.

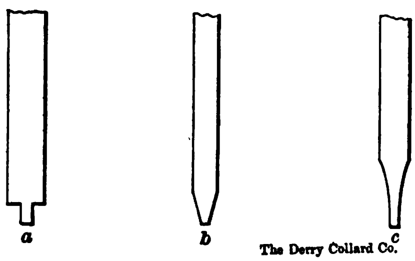


Figure 101. Styles of screw-driver points.

Now, a screw-driver, or any tool which must resist a bending or twisting strain, must be made in such a manner that the tension will be taken up for a considerable portion of the length of the article, thus doing away with a tendency to break at any one point. In Fig. 101, *b* represents a screw driver made in a man-

ner that apparently, according to some mechanics' minds, will just fill the bill. It is symmetrical, that is, there are no breaking points; but look at the end that enters the screw slot—it looks more like a chisel than a screw-driver. Now, when pressure is applied to this form, it, on account of the inclined sides, slips out of the slot. It will not hold, so a stick or piece of iron is placed on top of it in the form of a lever, and one or two men hold down on the end of this, as shown in Fig. 102, and the fellow doing the job gets a wrench on, and yanks. Now, the screw-driver is subjected to two strains instead of one. It tries to get out of the slot, and cannot, on account of the power applied above. It is also subjected to torsional strain from the direct pull of the wrench, and it breaks. Now, if it is made of the form represented at *c*, Fig. 101, and hardened and tempered *properly*, there will be very little danger of it breaking from any ordinary usage.

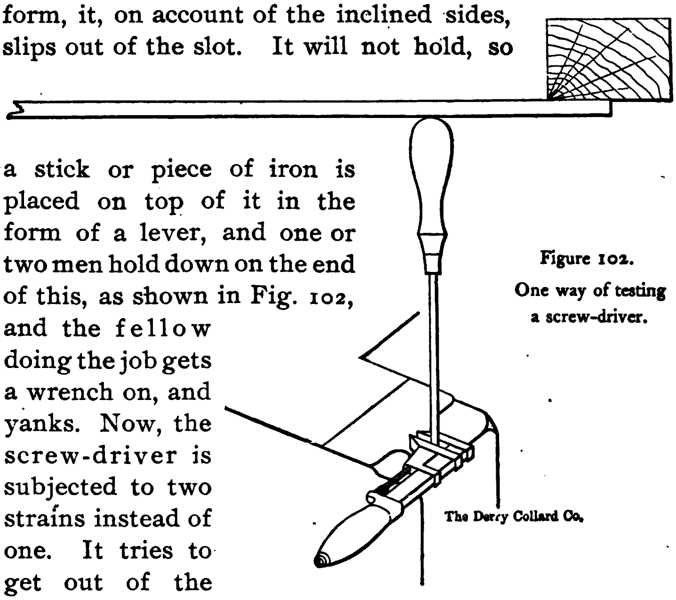


Figure 102.
One way of testing a screw-driver.

When heating for hardening, give it the lowest heat that will produce the desired result. Remember, hard-

ness is not the desired quality; it will not be called on to cut metals, it must simply resist strain or pressure, consequently toughness is the quality to be sought. Articles hardened in cold water do not show this quality to such a degree as those quenched in oil, so it is advisable to use oil as the cooling medium when it will answer. If oil will not answer, then heat the water. If it is a comparatively small screw-driver, heat the water nearly to the boiling point. The larger the article, the less heat it will be found necessary to give the water; but in no case, unless the steel is low in carbon and the screw-driver very large, should cold water be used.

The amount necessary to draw the temper varies with the percentage of carbon the steel contains. If it is made of ordinary tool steel, it may be heated until hardwood sawdust catches fire from the heat in the steel, or until a fine shaving from a hardwood stick, made by drawing the stick across the edge of the screw driver, catches fire, as noted before. When the proper temper shows, it may be quenched in warm oil or hot water, never in cold water.

While screw-drivers may seem like a small affair, hardly worth while thinking much about, the frequency with which they are used and the time lost in regrinding after breakage, make them quite an important tool in any shop. Then, too, the damaged screw heads must be counted against them.

Taper Mandrels.

When it is necessary to harden taper mandrels made of *tool steel*, it is necessary to provide some means of uniformly heating the article. One end, being of a

greater diameter than the other, has a tendency to heat slower. Owing to this fact, it will be necessary to heat slowly. When it has reached the desired heat, which should be uniform throughout, grasp by the small end with a pair of tongs and immerse in a bath of water or brine, which has a jet coming up from the bottom. When it ceases singing, remove and plunge in a tank of oil, allowing it to remain until it is cooled to the temperature of the bath. It should then be reheated to remove the tendency to crack from internal strains.

Counterbores.

The toolmaker or designer should, when designing tools that are to be hardened, avoid, as far as possible, sharp corners between portions of different sizes. If a counterbore is made as shown in Fig. 103, the presence

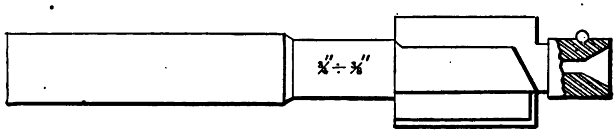


Figure 103. Counterbore with square corners.

of sharp corners is an invitation for the steel to crack from unequal contraction at these points. If the corners are rounded (filleted), as shown in Fig. 104, the tendency to crack is almost entirely eliminated.

Many times serious trouble arises from countersinking center holes too deeply in articles that are to be hardened. Fig. 104 represents a sectional view of countersinking in pilot, which is deep enough for all

practical purposes, while in Fig. 103, the countersinking is so deep that there would be a great tendency to crack when hardening. When articles of this description are countersunk too deeply, it is advisable to fill the hole with fire-clay before placing it in the fire. This plan, of course, would not work satisfactorily in the case of mandrels, arbors, and similar tools, whose centers must be hard in order to resist wear.

Heat to the lowest uniform red that will cause the

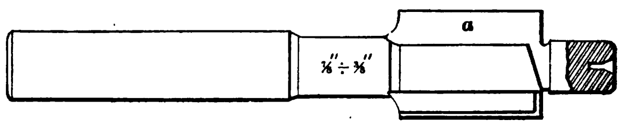


Figure 104. Counterbore with filleted corners.

article to harden, dip in a bath of lukewarm brine, hardening part way up the portion necked below size of shank.

When drawing the temper of counterbores, apply the heat at shank end, allowing it to run toward the cutting end of teeth.

The proper amount to draw the temper depends on the character of the work to be done, the design of the counterbore, etc. It was formerly the custom to draw the temper to a degree that made it possible to sharpen the cutting edges by filing with a sharp, smooth-cut file. If the counterbore is made of the design shown in Fig. 104, it may be sharpened by grinding on the face (a) of cutting tooth with an emery wheel, thus making it practical to leave the tool much harder than would otherwise be the case.

A very common mistake when making tools of this

description is to stamp any distinguishing marks on the tool when finished, thereby springing it; and unless this fact is noticed, the hardener will be blamed for it. *All stamping should be done before the important portions are to size.*

When hardening counterbores having inserted pilots, it is advisable to fill the pilot hole with fire-clay, in order to prevent the water entering. If the design is such that the tool is liable to crack when quenched, it should be dipped in the bath with the teeth uppermost. The contents of the bath should be warmed to reduce the liability of cracking.

Hardening Mandrels, Arbors, Etc.

Mandrels, arbors, and similar articles, which are to be hardened, are generally made of any piece of tool steel which comes handy. Now, it is a fact that tools of this description give a great deal of trouble when hardened, unless the operator is quite skillful. As the only reason for hardening a mandrel is to give it a hard surface and make it as stiff as possible, the desired result may be obtained by using a steel that is not high in carbon. Take, for instance, a steel containing 7/8 per cent. or one per cent. carbon. As good results can be obtained as if a steel containing 1 1/2 per cent. carbon were used, while the article would not be as liable to crack or spring as if a high carbon were used.

When making articles of this description, steel somewhat larger than finish size should be selected. The outside should be turned off and the piece annealed. After annealing, it may be machined to grinding size and then hardened.

When hardening, a fire large enough to heat the

piece uniformly should be used, and the piece turned frequently to insure good results. A mistake sometimes made in heating pieces of this description consists in using a fire too small to accomplish the desired result. One end and the center is heated, the end is reversed and the opposite end is heated. The first end, in the meantime, has cooled to a degree that makes it unsafe to quench the piece in the bath. So the second end is heated hotter than it should be, with the idea in view that the piece will again be reversed and the over-heated end will cool to the proper hardening heat, while the temperature of the opposite end is being raised to the desired heat. When it is taken from the fire, it is in the worst possible condition to harden; the center is too hot, one end is apparently about the right temperature, but the interior is not hot enough. The opposite end is possibly at about the right heat, but the interior is *too* hot. In this condition it is immersed in the bath and violent strains are set up, which result in the piece being cracked or sprung out of shape. Now, this is not at all right, yet it is so commonly practiced that the writer feels it necessary to caution the reader against a practice which is so radically wrong.

If obliged to use an ordinary forge, build a fire large and high enough so the piece may be uniformly heated; turn frequently; keep the piece well buried in the fire to prevent oxidation of the surface. When the steel reaches a low red heat, take it from the fire, sprinkle some pulverized cyanide of potassium on the surface. Place in the fire and bring to a uniform red heat, which must be a trifle higher than if there were teeth or projections on the surface, as, these being light,

would cool more quickly than a solid piece. If possible, use a bath having a jet of liquid coming up from the bottom. If it is a mandrel, it should be grasped by one of the ends with a pair of tongs of the description shown in Fig. 86. This insures hardening the body of the mandrel, and also allows the contents of the bath to have free access to the upper center, which would not be the case if a pair of tongs of the ordinary description were used.

It is essential that the *centers* of a mandrel be very hard. For this reason a method of quenching in the bath should be used that insures the centers in *both* ends hardening.

If it is considered best to draw the temper of the ends in order to avoid the corners chipping or the ends breaking, it is not advisable to make them as soft as the dead center of the lathe, which is usually drawn to very deep straw or brown color. The object attained in having the ends of a mandrel harder than the lathe center is that in case of wear, the center, being the softer of the two, will probably wear rather than the centers of the mandrel.

The piece should be worked up and down in the bath until it is of the same temperature as the contents of the bath, when it may be removed and heated somewhat to overcome the tendency to crack from internal strains. It should be held in a vertical position when dipping, in order to avoid springing.

Better results will follow if the piece is placed in a piece of pipe or tube when heating.

A very excellent method consists in placing the article in a piece of gas pipe, which is closed at one end. The hole in the pipe should be about one inch

larger in diameter than the piece to be hardened. Fill around it with granulated charred leather, having the mandrel in the center of the hole in the pipe, and the ends should not be within ½ inch of the ends of the pipe. Fill the pipe with the charred leather; place a loose-fitting piece of iron in the open end of pipe, and seal with fire-clay. When this is dry, the pipe may be placed in the fire and remain until the article is uniformly heated to the proper temperature, when it may be taken from the pipe and quenched, as described.

Still better results may be obtained if the piece is kept at a low red heat for a period of several hours, the time depending on the size of the piece. If ½ inch diameter or under, 1½ hours will be found sufficient. If larger, run correspondingly longer. When it has run sufficiently long, the piece may be removed from the tube, grasped by the tongs, as shown, and plunged in a bath of raw linseed oil, working up and down rapidly in the bath. This method receives further consideration in section on Pack Hardening.

Hardening Grooved Rolls.

When grooved rolls or similar articles are to be hardened, it is necessary to heat *very* uniformly. The projections, as shown in Fig. 105, have a tendency to heat faster than the balance of the roll. Should they become hotter, the projections will be very liable to crack or break off when quenched. As it is necessary to heat slowly in order to get uniform heats, the piece would be liable to oxidation on its outer surface, which is exposed to action of the products of combustion in

the fire and the air, if heated in an open fire. If small, it may be heated in a tube; if too large for this, it may be covered with the carbonaceous paste described in section on Methods of Heating. When the article has

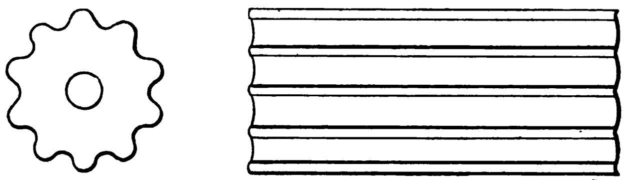


Figure 105. A grooved roll.

reached the desired uniform heat, it should be plunged in the bath in a *vertical* position. On account of the peculiar shape of the piece and the tendency of the steam generated, the contents of the bath should be agitated from the outside toward the center of the bath.

A method that gives very excellent results when hardening articles of this description is to use a bath having pipes coming up at the sides of the tank, as shown in Fig. 106. There should be a sufficient number of openings in these pipes to supply a generous quantity of water in order to produce the desired result. The water should be under sufficient pressure to project the contents of the bath against the piece being hardened, with enough force to drive the steam away, so the water can readily come in contact with the heated surface.

If the pieces are short and not too large, they may be heated in red-hot cyanide, dipping in a bath of the form described.

If it is not necessary to harden very deeply, the

article may be removed from the bath when hardened sufficiently and placed in a tank of oil, leaving them in the oil until the steel is uniformly cooled to the tem-

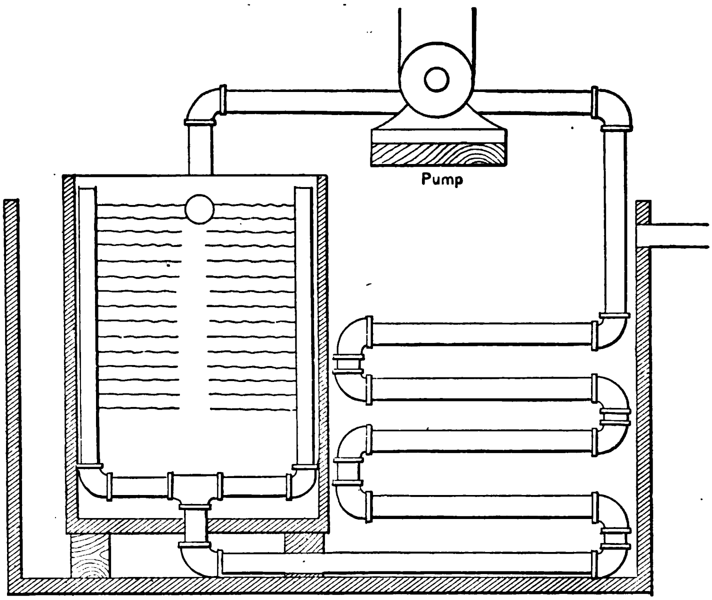


Figure 106. Bath for hardening grooved rolls.

perature of the oil. It is extremely important when hardening pieces of this description that they be reheated as soon as possible after removing from the bath to overcome the tendency to crack from internal strains. The longer they remain under strain, the

more likely they are to crack later without any apparent cause. Every mechanic can recall cases of this kind.

Hardening the Walls of Holes.

A peculiarity of a cylindrical piece of steel is that, when hardened, it is liable to become oval in shape. This is especially true of pieces having holes running through their centers, as shown in Fig. 107. When it is possible, or is considered advisable to grind the piece inside and outside after hardening, the amount it goes out of shape need not in any way interfere with the utility of the tool, provided there has been a sufficient allowance of stock made for grinding.

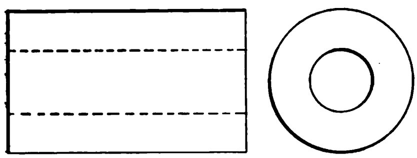


Figure 107. Piece with hole through center.

If, however, there is no means at hand for grinding the piece after hardening, it becomes necessary to harden in a manner that does away with the tendency of the piece going out of shape or the hole contracting very appreciably. This may be accomplished in the case of such articles as ring gauges, reducing

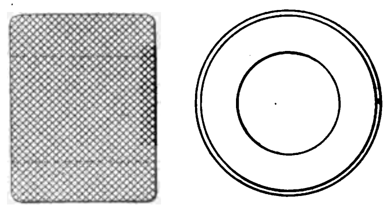
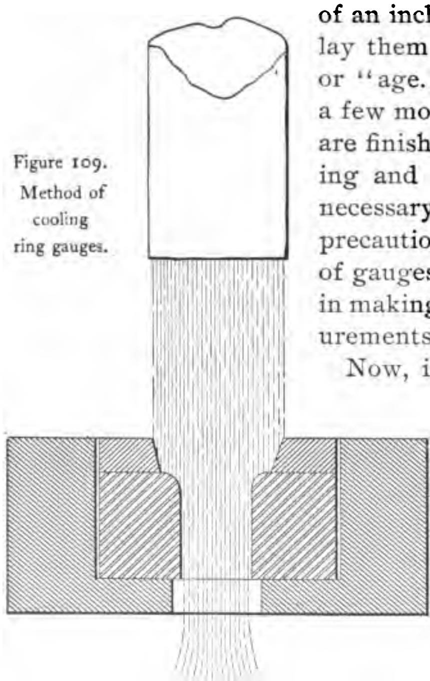


Figure 108. Gauge with hole through center.

dies, and any tools which do not require hardening on their outer circumference, if proper care is taken.

When gauges of this description (as shown in Fig. 108) are hardened by the ordinary methods, it is necessary to rough-grind them to within a few thousandths of an inch of finish size and lay them away to "season" or "age." After laying for a few months or a year, they are finished to size by grinding and lapping. It is not necessary to observe this precaution except in the case of gauges that are to be used in making *very accurate* measurements.

Figure 109. Method of cooling ring gauges.



Now, it is not always desirable to wait a year after a piece of work is hardened before grinding to size and using. In order to overcome the tendency of alteration of sizes and shapes as the piece ages, it may be hardened in a manner that gives the walls of the hole sufficient hardness to resist wear, yet leaving the circumference soft. This can be accomplished by heating the piece very carefully to the required heat and placing in a hole a trifle larger than the outside of the

piece. Now place a piece of metal having a hole somewhat larger than the hole in the gauge on top of the piece, as shown in Fig. 109. A stream of water may now be turned on in such a manner as to readily pass through the hole, thus cooling the walls and hardening them. The balance of the stock, being protected, does not harden. The walls of the hole being hard and inflexible do not yield as the piece grows cold. And as the outside portion of the piece is hot and yielding, it does not necessarily contract in the direction of the hole, thus reducing the tendency of alteration of size of the hole.

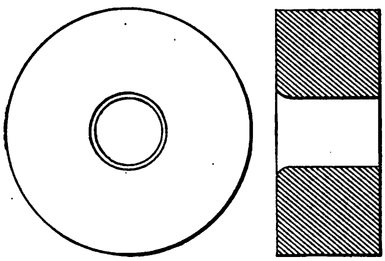


Figure 110. Die for reducing cartridges.

Dies used for reducing the size of gun cartridges, Fig. 110, and similar pieces, are hardened by this method, and give excellent results, because the outside, being soft, will have no tendency to break from the pressure exerted when the die is in use.

As there is very little tendency of alteration of size and shape of the hole, it can be lapped to size without grinding. In case it is not to be ground, there need be but a small allowance for lapping, provided the hole is smooth and straight.

As is customary when dies of this description become worn, they may be closed by heating red-hot and being driven into a taper hole. This diminishes the size of the hole in the die, which may then be reamed to size

and rehardened. In order to get good results, it is advisable to anneal the steel after closing in, or the molecules of steel will not assume their proper relations when hardened.

Articles with Holes Near One Edge.

When hardening articles having holes near the edge, extreme care must be observed, as the unequal contraction occasioned by the form of the piece will make it very liable to crack. A piece of the form shown in Fig. 111, represents an example of the form mentioned. While such a piece could be hardened by the pack-hardening process with no liability of its cracking if it were quenched in a bath of oil, it would not always be considered advisable to use this method, so it becomes necessary to heat the article in some form of fire, and quench in water.

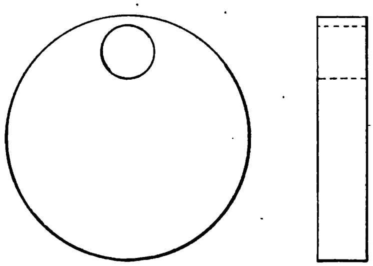


Figure 111. Piece with hole near edge.

The piece should be heated very carefully and no hotter than is necessary to accomplish the desired result. It will be necessary to use the utmost care in heating, because if the thin portion of stock between the hole and the circumference of the ring were heated any hotter than the balance of the piece, it would surely crack at this point.

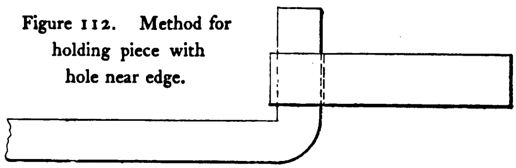
When dipping in the bath, the heavy portion should

enter the bath first, the thin portion should be uppermost in order that it may enter last.

If it is not essential that the walls of the hole be hard, it may be filled with fire clay, previous to placing in the fire. If treated according to this method, the danger of cracking is reduced to the minimum.

A method employed very successfully in some shops when hardening articles of this description, consists in

Figure 112. Method for holding piece with hole near edge.



bending a piece of wire in the form of a hook. This hook is heated red hot on the bent end, and when the article is at a uniform heat, the red hot end of the hook is inserted in the hole near the edge, as shown in Fig. 112, and the article immersed in the bath. The heavy portion will, of course, enter the bath first, the wire being red-hot will prevent the thin portion cooling as rapidly as it otherwise would. The size of the wire must be determined experimentally; that is, if many pieces are to be hardened, the size of wire that gives best results should be used, but in no case should it fill the hole when the pieces are cold.

The bath should be warmed somewhat in order to reduce liability of cracking.

Wood-Working Tools.

There are many methods used in hardening tools used for cutting wood, the different methods varying

according to the nature of the steel used and the use to which the tool is to be put when finished. The more common method is to heat in an open fire and plunge in water, drawing the temper until the brittleness is reduced to a point that makes it possible for the tool to stand up when in use. By this method, it is necessary to draw the temper quite low in order to get a degree of toughness that enables the tool to stand up well.

A method that is practiced in many shops is to heat in a muffle furnace or in a tube, hardening in a bath of water having oil on its surface, as shown in Fig. 82, the depth of oil depending on the desired amount of hardness. Some hardeners claim to be able to gauge the amount of hardness by the depth of oil to a nicety, that makes it unnecessary to draw the temper after hardening. The writer cannot vouch for this claim, as he has never seen it done when hardening wood-working tools, but has been able to accomplish it when certain kinds of iron-working tools were hardened.

Another method consists in heating the tool in a crucible of red-hot lead, or in a crucible of red-hot cyanide of potassium, dipping in a bath of oil, to which has been added a quantity of alum. The exact amount cannot be stated, as he has found it to vary when applied to hardening steels of various percentages of carbon. The use to which the tool is to be put when hardened, has a great deal to do with the composition of the bath.

As brittleness is *not* a desirable quality in wood-working tools, it is necessary to harden in a manner that insures toughness in the hardened product. For this reason it is not advisable to use a bath of cold liquid of any kind.

Mixture for hardening wood-working tools.

If the cutters are light on the cutting portions, the bath may be heated considerably, the temperature depending on the shape and size of the tool and the steel used in its construction.

Various animal or vegetable oils are used for quenching tools of this description, either separately or mixed with varying proportions of tallow. Melted tallow is many times used with success, heated to a temperature that gives good results when applied to the individual piece of work. The amount necessary to draw the temper depends on circumstances and can not be arbitrarily stated, but it is generally found to be between a brown and a dark blue color.

A method employed in some shops when hardening wood cutting tools consists in heating to a low red and plunging in a mixture of molten lead and tin in the following proportions: Lead, 7 parts; tin, 4 parts, which melts at about 440° Fahr.

The cutters are heated to a low red and plunged in this mixture at the temperature mentioned, allowed to cool for a short time, then removed and cooled in water. They will be found to be exceedingly tough, and capable of holding their edge in a satisfactory manner.

Unless this method is used in a painstaking manner, it had better not be tried, as anything but satisfactory results will follow.

If many cutters are to be hardened, it will be found necessary to gauge the heat of the bath by use of a thermometer.

Fixtures for Use in Hardening.

In order to attain certain results, it is necessary at times to make fixtures for holding the work. These

fixtures are designed to protect certain portions of the piece of work from the action of the contents of the bath.

The writer was at one time in charge of work in a

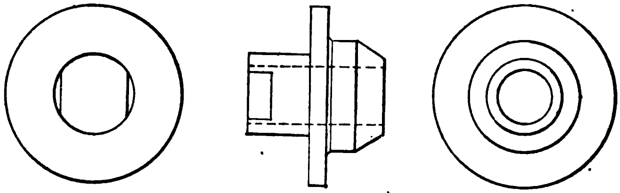


Figure 113. A hard piece to harden.

shop manutacturing bicycles. In order to accomplish a desired object, the axle cones, which had formerly been made of machinery steel, were made from a high grade of tool steel. The front axle cone was of the

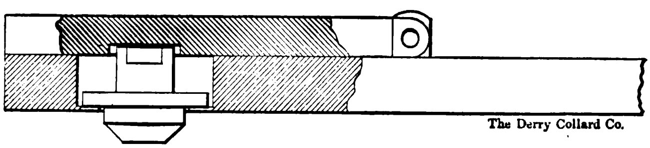


Figure 114. Device for hardening piece shown in Figure 113.

shape shown in Fig. 113. It was necessary to harden the beveled portion extremely hard, in order to resist wear. It was found very difficult to harden this portion without hardening the flange. If this were hardened, it showed a tendency to break when in the wheel, as it was very thin.

In order to harden the bevel and leave the flange

soft, a fixture was made, as shown in Fig. 114. The cone was heated in a crucible of red-hot lead. When it reached the desired temperature, the cover of the fixture was raised and the cone taken from the lead by means of a wire hook made for the purpose. It was placed in the fixture, as shown, the cover lowered, and the fixture immersed in a bath of water, working it around well until the cone was cold, when the fixture was inverted over a tank of boiling water, and the cone dropping into this and remained until a sufficient quantity was in the catch pan, Fig. 45, to warrant emptying it. This tank was found very valuable, as it furnished a means whereby the strains incident to hardening could be removed, and at the same time the temper was drawn sufficiently.

Pack Hardening.

When articles which are *small* or *thin* are heated to a red and plunged in oil, they become hard enough for most purposes, but not as hard as if immersed in water. Articles hardened in oil seldom crack from the effects of cooling, as the heat is not absorbed as quickly as if water were used, neither are they as likely to spring.

The fact that articles quenched in oil showed no tendency to crack, and very little liability to spring, has led the writer to make exhaustive experiments in perfecting a method whereby articles which gave trouble when hardened by ordinary methods might be

hardened in oil and produce a surface as hard as if it were heated red-hot and plunged in water. The results have been more gratifying than were ever dreamed of before trying. It is not claimed that this method was originated by the writer. It was suggested by a man in his employ, who had seen it practiced with varying results in a shop where he formerly worked.

The fact that milling machine cutters, punch press dies, and similar articles, could be treated in such a manner that they might be hardened in oil without danger of cracking, led to experimenting, which resulted in a method whereby tools could be hardened with *absolutely* no danger of cracking. The tendency to spring was also reduced to the minimum. Unexpected results were accomplished in some ways, for it was found by experience that milling machine cutters could be run at a periphery speed, two, and in some cases four, times as great as when a similar cutter made from the same bar was heated red-hot and plunged in water. Punch press blanking dies would do from six to ten times the amount of work as when hardened by methods formerly used.

It was also found extremely satisfactory when applied to taps and screw thread dies, because the tendency to alteration of pitch was reduced to the least possible amount. Neither would they change so far as diametrical measurements were concerned. Gauges hardened by this method gave results fully as satisfactory as other articles hardened in a similar manner. Long reamers, stay-bolt taps, and similar tools, have been hardened by the thousands and shown results more than satisfactory.

Tool steel is made with a sufficient quantity of

carbon to harden in a satisfactory manner and accomplish the results intended when the tool is made. To make steel with a higher percentage of this hardening element, and put it on the market, would be folly, as the average man hardening steel would treat it the same as the ordinary tempers are treated, with the result that the tools made from it would be ruined when hardened.

Now, tool steel may be treated with carbonaceous materials when red-hot, with the result that the surfaces will be extremely hard if the article is quenched in oil. The depth of the hardened surface depends on the length of time the article is subjected to the carbonizing element. In order to accomplish the desired result, the piece of work must be packed in a hardening box with the carbonaceous material; the top must be closed with a cover slightly smaller than the opening in the box, and the space between the cover and sides of the box covered with fire-clay. This operation is familiarly known as sealing. Sealing the box has the effect of preventing the gases escaping. It also prevents the direct heat of the fire from entering the box, as that would be very injurious to the steel. Then again, the oxygen in the air is excluded from the box, or, if present in a degree, does not oxydize the surface of the piece, as it is taken up by the packing materials in the box.

It is very necessary when charging steel by the process under consideration, that a carbonizing material be used which contains no elements injurious to tool steel. For this reason no form of bone should ever be used, as bone contains a very high percentage of phosphorus, and phosphorus, when present in tool

steel, has the effect of making it extremely brittle. The processes the steel maker puts the steel through in order to remove injurious impurities is one reason of its high cost as compared with the ordinary cheap grades of steel. The lower the percentage of phosphorus, the more carbon it is safe to have in the steel; so it will readily be seen that any process which results in an addition of this harmful impurity should never be used. The writer has used a mixture of equal parts, by measure, of granulated charcoal and granulated charred leather in most of his work for the past nine or ten years with the best results; although in exceptional cases, where extreme hardness was desired, charred leather alone was used.

The work is packed in a hardening box. This box may be either wrought iron or cast iron. Best results are claimed by some when wrought iron boxes are used. But the writer has never in practice been able to notice any difference, so he has used cast iron boxes altogether for the past eight years, as they are cheaper and more readily obtained. The work should be placed in the box in a manner that does not allow any of the pieces to come within 1½ inches of the bottom or top of the box, or within 1½ to 1¾ inches of the sides or ends, for two reasons. If they are placed too near the walls of the box, they are affected by every change of temperature in the furnace. Then again, cast iron has a great affinity for carbon, and will extract it from a piece of tool steel if it comes in contact with it. If one end of an article, packed as described, comes in contact with the walls of the box, the piece will not harden at that point, or, if it does, it will not be as hard as the balance of the piece. And, as a chain is no stronger than its

weakest link, so a hardened tool is no better than its softest spot, provided it is on any cutting portion, because, when that dulls, the whole tool must be ground.

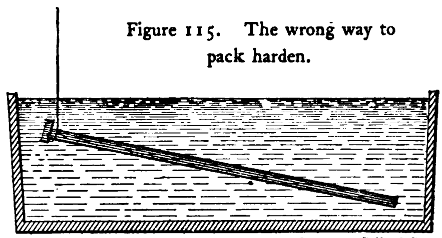
This method of pack hardening is not only a means of getting good results, but when work is hardened in large quantities, it is a much cheaper method than that ordinarily used, because quite a number of pieces may be packed in the box at a time. Or, if the furnace used is of sufficient capacity, several boxes may be heated at the same time.

When packing work in the hardening box, place about 1 ½ inches of packing material in the bottom, then lay a row of work on this, being careful that no pieces come within ½ inch of each other, or within 1 ½ inches of the walls of the box. Cover this row of work with packing material to the depth of ½ inch, put in another row of work, and continue in this way until within 1 ½ inches of the top of the box. After covering each row of work with the packing material, it should be tamped down lightly to insure its staying in place. When the box is filled to within the distance of top mentioned (1 ½ inches), the balance should be filled with packing material, the cover put in place and sealed with fire-clay mixed with water to the consistency of dough, and allowed to dry before placing in the furnace.

Before the articles are packed in the box, a piece of *iron* binding-wire should be attached to each piece of work in such a manner that the article may be removed from the box and dipped in the bath by this means, unless the piece is too heavy to be handled in this manner, in which case it must be grasped with a pair of tongs. The wires should extend up the sides to the top of the box and hang over the edge, in order

that the operator may readily see them when removing the articles from the box. If several rows of work are placed in the box, it is necessary to place the wires in a manner that allows the different rows to be readily distinguished. As it is necessary to draw the pieces on the top row first, each succeeding row should be drawn in its order, because if an article were drawn from the bottom row first, it would probably draw one or more of the pieces located above along with it. As a consequence they would lay on the top of the box exposed to the action of the air, and would cool perceptibly while the first piece was being quenched in the bath. For this reason it is advisable to draw the pieces in the top row first, as described.

Figure 115. The wrong way to pack harden.



As the length of time a piece of steel is exposed to the carbonaceous packing material after it is red-hot determines the depth of hardening, articles packed in a box should all be of a character that need carbonizing alike, or some pieces will not receive a sufficient depth of carbonizing and others will receive too much. Knowing this, one may select the articles accordingly, packing those requiring charging for one hour in one box, those requiring two hours in another, and so on. A little experience will teach one the proper length of time to give a tool of a certain size to accomplish a given result.

Boxes for pack hardening.

Attention must be paid to the shape of the piece when packing in the box. If it is long and slender, it should not be packed in such a manner that it will be necessary to draw it through the packing material, as shown in Fig. 115, or it will surely spring from doing so, it being red-hot, and consequently easily bent. If but a few pieces of this character are to be hardened, it would not be advisable to procure a box especially

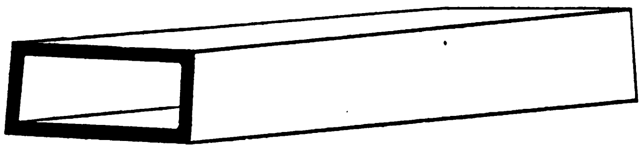


Figure 116. Box for pack hardening.

adapted to it. In that case the articles could be packed two or three in a box. When they have run the proper length of time, the box should be removed from the furnace, turned bottom side up on the floor, provided the floor is of some material that will not catch fire. The piece of work may be pulled out lengthwise from the mass, and in that way all danger of springing is done away with.

If, however, quite a number of pieces are to be hardened, it is advisable to procure a box adapted to pieces of this description. This may be done by adopting a design opening at the end, as shown in Fig. 116. This may stand on end with the opening uppermost while packing the pieces. If a furnace of the design

shown in Fig. 117 is available, it should be used, as the box can stand on end. If this form of furnace is not at hand, the box may be placed on its side in any furnace large enough to receive it. If necessary to use a furnace where the box must lay on its side, it will be advisable to provide some way of fastening the cover in place. This may be done by drilling a $\frac{1}{2}$ inch hole on opposite sides of the box and running a rod at least $\frac{1}{16}$ of an inch smaller than the hole across the face of the cover, Fig. 118, before sealing with fire-clay. This rod can easily be removed when the articles are ready for immersion in the bath.

In order that the exact time at which the work becomes red-hot may be ascertained, it will be necessary to use test wires. Several $\frac{1}{4}$ inch holes may be drilled near the center of the cover, a $\frac{3}{16}$ inch wire run through each of these holes to the bottom of the box, as shown in Fig. 26. When the work has been in the furnace for a sufficient length of time to become heated through, according to the judgment of the operator, one of the test wires may be drawn and its

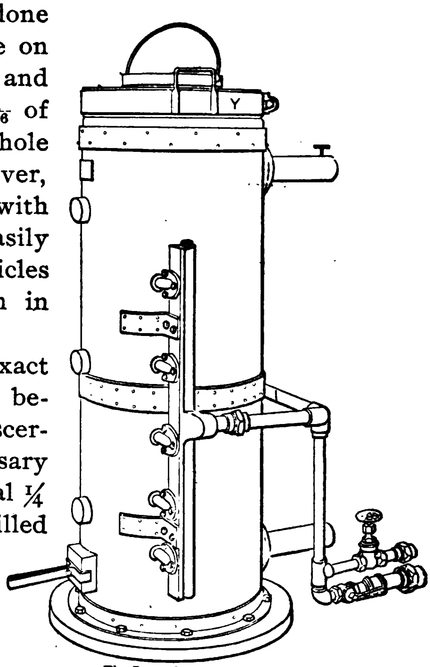


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Figure 117. Furnace for use in pack hardening.

condition noted. If it shows red-hot the entire length, note the time. If not, wait a few minutes (say, 15 minutes) and draw another wire. When one is drawn that shows the proper temperature, time from this.

The length of time the pieces should be run cannot

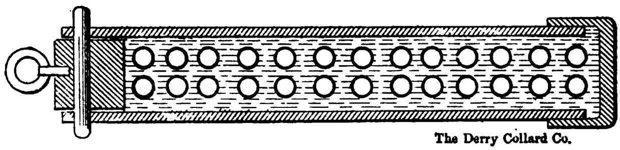


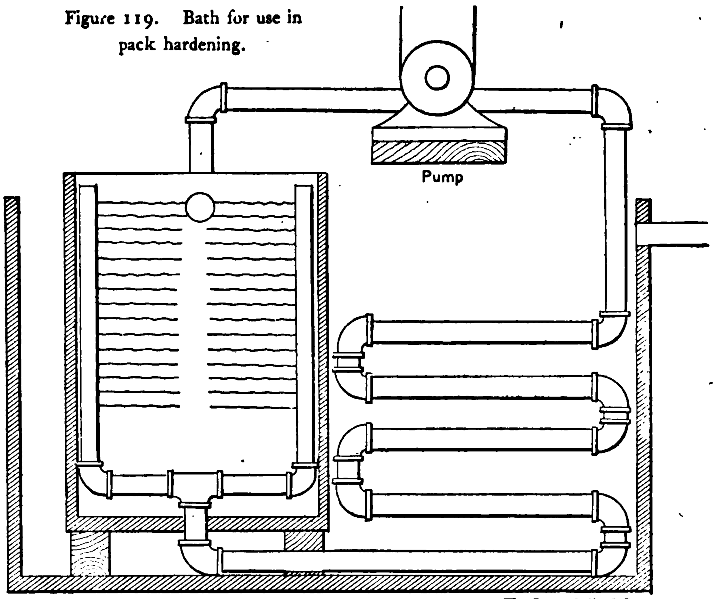
Figure 118. Method of fastening cover in place.

be stated arbitrarily, as the character of the work to be done by the tool must, in a measure, determine this. However, if the pieces are ½ inch diameter, and are to cut a soft grade of machinery steel, one hour may be found sufficient. If a harder surface is required, it is necessary to run somewhat longer (say, 1½ hours). When the work has run the required length of time, the box may be removed, the cover taken off, and the articles taken out one at a time and dipped in a bath of raw linseed oil. When the articles are long, it is advisable, if possible, to use a bath having a perforated pipe extending up two opposite sides of the tank, as shown in Fig. 119. A pump should be connected with the oil in the bath, pumping it through a coil of pipe in a tank of water and forcing back into the tub through the upright perforated pipes shown. This method insures evenly hardened surfaces, as the jets of oil forced against the sides of the article drive the vapors away from the piece, thus insuring its hardening. It is necessary to move the work up and down and to turn

it quarter way around occasionally in order to present all sides to the action of the oil.

When milling machine cutters, or similar tools having projections, are to be hardened by this method, they should be packed in the box, using the packing

Figure 119. Bath for use in pack hardening.



material mentioned. Previous to placing the cutters in the hardening box, a piece of iron binding-wire should be attached to each cutter and allowed to project over the edge of the box. Test wires should be run down through the holes in the cover, as shown in Fig. 26. The length of time the cutters should run is determined by the character of the work they are to do; but for

ordinary milling, a cutter 3 inches diameter, if of the ordinary design, should run about 3 hours.

If the teeth are heavy, of the style known as formed mills, Fig. 120, they should be run 4 hours after they are red-hot. When the box is removed from the furnace, the cutters may be removed one at a time, placed on a bent wire of the form shown in Fig. 81, and immersed in the oil, working them around well until all trace of red has disappeared, when they may be dropped to the bottom of the bath and left until cold.

A milling machine cutter of the form shown in Fig. 120 will not as a rule require tempering. The teeth may be left as hard as they come from the bath, but those of the ordinary form of tooth should have the temper drawn. This may be done by the method described under Hardening and Tempering Milling Machine Cutters, or, if there are many cutters, a saving of time will result if the articles are placed in a kettle of oil and the temperature gauged by a thermometer, drawing them to 430 degrees.

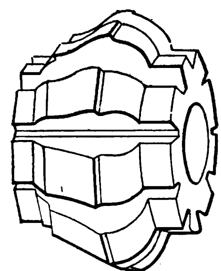

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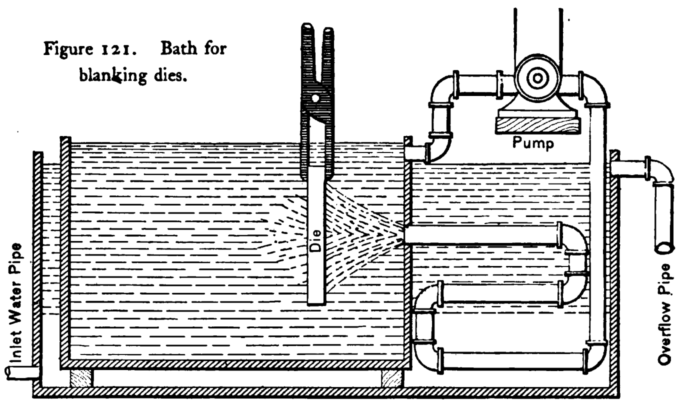
Figure 120. Formed milling cutter.

Punch press blanking dies give excellent satisfaction if hardened in this manner. The die is packed in a box. Test wires are run down through the opening in the die to the bottom of the box. When drawing the wires to test the heat, do not draw them way through the cover. After observing the heat, place the wire back in its original position. A wire can be raised from time to time, the amount of heat observed and the wire

returned. In this way the operator can tell from time to time the exact temperature of the piece being heated, and as the same laws governing the heating of steel in the open fire apply when heating to harden by this method, it is advisable to keep the heats as low as possible; for steel treated by this method will harden in oil at a lower heat than if treated in the ordinary way and hardened in water.

Blanking dies for the class of work usually done on punch presses (if they are 1 inch to 1½ inches thick)

Figure 121. Bath for blanking dies.



should run about four hours after they are red-hot. At the expiration of that time the box may be removed from the furnace, the die grasped by one end with a pair of tongs and immersed endwise down into a bath of raw linseed oil. It is a good plan to have the bath rigged as shown in Fig. 121. A pipe is connected with the tank near the top, and runs in a coil through a tank of water. A pump draws the oil from the tank through the coil, and forces it back into the bath, as represented.

The inlet pipe may be so situated as to cause the oil to circulate with considerable force through the bath. This, striking the face of the die, passes through the opening, insures good results. If no means are provided for the circulation of the oil, the die may be swung back and forth in the oil, and it will harden in a satisfactory manner. Forming and bending dies, if hardened by this method, must be run longer, and heated somewhat hotter, yet not hot enough to injure the steel.

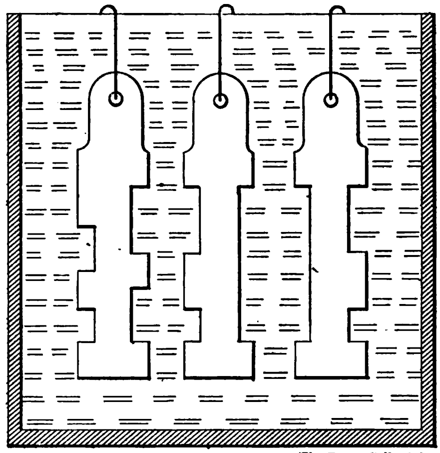

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Figure 122. One method of packing snap gauges.

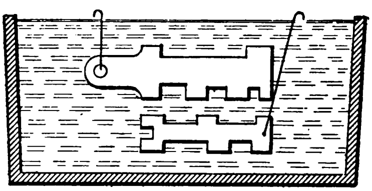

Figure 123. Another method of packing snap gauges.

Pack hardening furnishes a method whereby taps may be hardened without altering the pitch very perceptibly; neither will the diametrical measurements be changed, provided the blanks were annealed after blocking out to shape, and by this method the teeth are made exceedingly hard without being brittle. A tap from one to two inches

in diameter should be run about two hours. It should be worked around rapidly in the bath, in order that the teeth may be hardened. For general machine shop work, taps do not require the temper drawn as low as if they were hardened by heating red-hot and plunging in water. Generally speaking, 430 degrees (a faint straw color) is sufficient, provided a low heat was maintained in the furnace.

This is an ideal method of hardening gauges and similar work, as the liability of cracking is eliminated and the danger of springing is reduced to the minimum. If the gauge is of the plug or ring form, it is not necessary to allow as great an amount for grinding as would otherwise be the case, as there is little danger of springing.

When hardening snap gauges, especially if they are long, it is advisable to pack as represented in Fig. 122, provided a box deep enough is at hand. If obliged to pack in a box so that the gauges lay lengthwise in the box, they should be so placed as to have the edges up and down, as shown in Fig. 123, thus doing away with the tendency to spring when they are drawn through the packing material.

Articles of a form which betokens trouble when hardening can, if proper precautions are taken, be hardened by this method in a very satisfactory manner. Take, for instance, the shaft shown in Fig. 124. This was made of ⅞ per cent. carbon crucible steel, and turned within a few thousandths of an inch of finish size. It was packed in a mixture of charred leather and charcoal, and subjected to heat for 1½ hours after it was red-hot. It was then dipped in a bath of raw linseed oil, heated to a temperature of 90°. It was found

upon being tested between centers to run nearly true.

The designer does not always take into consideration the difficulties which may be encountered when a piece of irregular contour is hardened, consequently we sometimes run across articles which call for serious study on the part of the hardener when the article reaches him. Then again, such articles are many times made

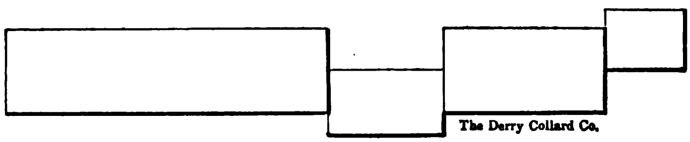

Figure 124. A peculiar piece to harden.

of a *high* carbon *tool* steel, when a low grade steel would answer the purpose as well, and not cause nearly as much trouble.

At one time the writer was called to a shop where they were experiencing all kinds of trouble in an attempt to harden a gauge of the description shown in Fig. 125. As it was not practical to grind the interior of this gauge with a grinding machine, it was necessary that it should retain its shape when hardened. In order to accomplish this, the gauge was surrounded with a mixture of fire-clay, to which was added sufficient hair (obtained from a plasterer) to hold it together. It was moistened with water to the consistency of dough. The hole in the gauge was filled with finely granulated charred leather.

It was then placed in a small hardening box, in the bottom of which was placed 2 inches of granulated wood

charcoal. The box was filled with charcoal, the cover placed in position, and sealed with fire-clay.

The box was subjected to heat for one hour after the contents were red-hot, this being ascertained by means of the test wires, as described. The gauge was then taken from the box, the leather removed from the hole, and a jet of raw linseed oil

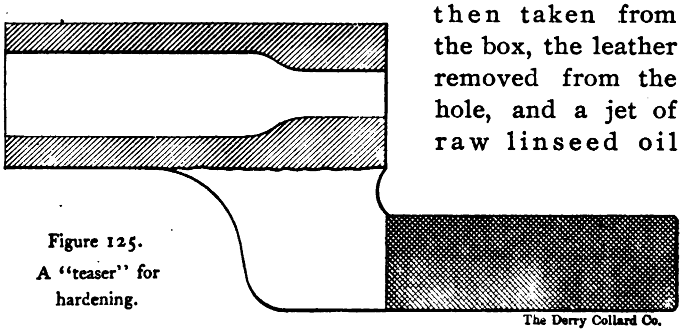

Figure 125.
A "teaser" for hardening.

forced through the hole until the piece had cooled off. The walls of the hole were very hard, and the gauge was found by test to have retained its shape. The coating of fire-clay prevented the exterior hardening of the piece, thereby eliminating the tendency to spring or go out of shape. The walls of the hole, hardening *first*, retained their shape, and the balance, being red-hot, conformed to this portion.

While it would be impossible to enumerate the various articles of irregular contour that may be hardened by applying this principle—namely, protecting the portions that do not require hardening, by the use of a mixture of fire-clay and water, adding sufficient hair to hold it together—it can safely be said that many thousand dollars' worth of tools are ruined annually, which might have been saved had this precaution been observed.

Pack hardening for mandrels and arbors.

As this process of charging the surface of the steel with carbon is a process of cementation, it is necessarily slow. When extremely high carbon steel is used in making tools, it is considered advisable by some to use hoofs and horns as packing material rather than leather. At times it is not considered desirable to subject the articles to heat for so great a length of time. In such cases it is necessary to treat the surfaces to be hardened with some material that will act more quickly than charred leather. In fact, at times it is necessary to prevent any portion other than the ones to be hardened from becoming red-hot.

This can be effected by covering the parts with the fire-clay mixture to a considerable depth, applying heat to the portions that need hardening. When it is not desirable to subject the article to heat for a length of time sufficient to charge the steel with the necessary amount of carbon to cause it to harden (if it was to be carbonized by means of charred leather), excellent results may be had by the use of a mixture of 5 parts of rye flour, 5 parts table salt, 2 parts yellow prussiate of potash, filling the hole or covering the portions to be hardened with this.

Mandrels, or any form of arbor which it is considered advisable to harden, will harden in a more satisfactory manner by this method than by any that has come to the writer's notice. If the article is long and slender, do not pack in the box in such a manner that they will spring when drawn out; but if the shape of the box is such that this cannot be avoided, the box may be turned bottom side up on the floor when the articles are ready for hardening, as previously explained. If, however. the mandrels are made of the proportions

usually observed when making for general shop use, there is very little liability of springing when drawing them through the packing material. The mandrel may be wired as represented in Fig. 126, or it may be grasped with a pair of tongs of a form that allows the contents of the bath to have ready access to the end of piece; but as tongs of this form are not in general use, the wires will answer unless the pieces are very heavy. In this case it is advisable to procure tongs of a suitable shape rather than to have an unsatisfactory article when it is finished. As stated under Examples of Hardening, it is never advisable to hold a mandrel with any form of tongs that in any way interfere with the hardening of the walls of centers in the ends of a mandrel.

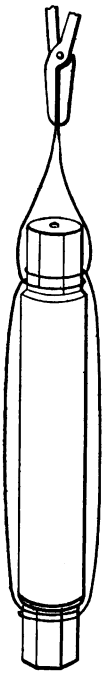

Figure 126. How to dip in bath.

If the work is wired, it should be done in a manner that makes it possible to dip the mandrel in the bath in a *vertical* position, to avoid any tendency to spring. The wires may be grasped by means of tongs which close together very nicely, as shown in Fig. 126, in order that they may not lose their grip and the piece fall to the bottom of the bath before the red had disappeared from the surface. It should be worked up and down in the oil until all trace of red has disappeared, when it may be lowered to the bottom and left until cooled to the temperature of the bath.

Circular forming tools, especially those having long, slender projections and sharp corners, as shown in Fig. 127, are safely hardened by this process, as they

can be given any degree of hardness desirable without making them brittle. Being solid in form, they must be heated for a longer period of time than if there were teeth on the surface—as a milling machine cutter. As with other cutting tools, the length of time a tool of this form should be subjected to heat depends on the nature of work to be performed by it. A tool 4 inches in diameter and 2 inches wide for ordinary work should run about 4 hours after it is red-hot. If there are slender projections from the face of the tool, it will be found necessary to draw the temper somewhat; but as a rule it should not be drawn as low as if it were hardened by the methods ordinarily employed.

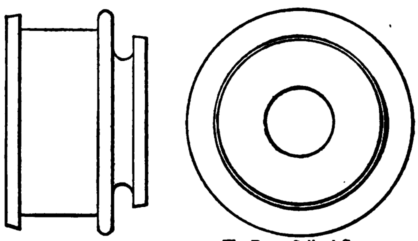
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Figure 127. A forming tool.

The writer has in mind a forming tool of the same general outline as the one represented in Fig. 127, which gave excellent results when drawn to 350 degrees after hardening by the method under consideration. It was hard enough to stand up in good shape, and yet tough enough to stand very severe usage.

If the formed surface is of a shape that insures strength—that is, if there are no projections—the cutter should be left as hard as when it comes from the bath.

Stay-bolt taps and similar tools may be packed in a box of the proper shape and run for a length of time, depending on the size of the piece. They should then

be taken one at a time and immersed in a bath of raw linseed oil and worked up and down in a vertical manner, moving to different parts of the bath, unless there is a jet of oil coming up from the bottom. Or, better still, having perforated pipes coming up the sides of the bath, as represented in Fig. 119. In either case it is advisable to work the articles up and down, to avoid the vapors which always have a tendency to keep the contents of the bath from acting on the heated steel.

If the articles are long, a deep tank should be used for the bath. If the taps are 24 inches long, there should be a depth of 40 inches of oil. If the articles are longer, the tank should be proportionally deeper.

A precaution that should always be observed when hardening *large* pieces of work, when they are to be quenched in a bath of oil, consists in protecting the hands and arms of the operator to prevent burning from the fire, which results when a piece of red-hot steel is immersed in oil. This is, of course, simply a burning of the surface oil as the steel passes through it, but it is liable to flash high enough to burn the hands and arms unless they are protected in some manner.

When hardening *long* articles, it is found much more convenient if the tanks containing the cooling liquid are so located that the tops of the tanks are nearly on a level with the floor—say 12 or 15 inches above it.

The toolmaker should, when making adjustable taps, reamers, etc., of the description shown in Fig. 128, leave a portion on the end solid, as shown in Fig. 129, to prevent the tool springing out of shape. The hole for the adjusting rod should be filled with fire-clay, the article packed with the mixture of charcoal and

charred leather, and subjected to a very *low* red heat, and dipped in raw linseed oil, warmed to about 90 degrees Fahr. The length of time it should be subjected to heat after it is red-hot depends on the size,

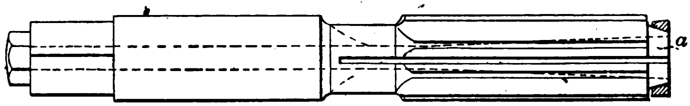

Figure 128. An adjustable reamer.

quality of steel used, and the work it is to do. It will vary from 1 to 2½ hours. The temper may be drawn to a light straw or a full straw color. The shank, and ends of flutes nearest the shank, should be drawn to a blue. When drawing the temper, the reamer or tap may be placed in a kettle of oil heated to the proper degree for the cutting edges. The shank may be drawn lower in a flame, or heat may be applied at the shank end by means of a flame from a gas jet, Bunsen burner, or any other means, allowing the heat to run toward the cutting end. After the reamer has been hardened and ground to size, the extreme end may be ground off enough to allow the slots to extend to the end.

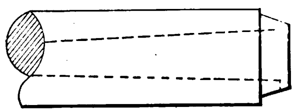

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Figure 129. Solid portion of reamer.

Dies used for swaging tubing are a source of annoyance when hardened by methods usually employed, as the unequal sizes of the different portions cause them to spring out of shape, and their shape is such that it is next to impossible to grind them in a manner that insures satisfaction when they are used.

Pack hardening furnishes a method whereby this

class of work can be made hard enough to do the work required of them, and they do not alter in shape enough to require grinding. For this reason the extremely hard surface, which comes in contact with the contents of the bath, need not be removed by grinding.

When making swaging dies of the description mentioned, best results will follow if they are made of tool steel of 1⅛ to 1¼ per cent. carbon. Block to shape, anneal thoroughly, and finish to size. When hardening, the dies should be wired and packed in a box, as shown in Fig. 130, placing charred leather all around the die for a distance of ¾ inch to 1 inch. The balance of the box may be filled with packing mixture that has previously been used. Run for about 4 hours after they have reached a medium red heat. It is necessary to give articles of this description a trifle higher heat than if hardening cutting tools made from the same stock.

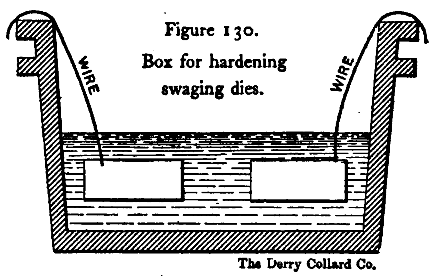


Figure 130.
Box for hardening swaging dies.

As hardness is the required quality, the dies should be left as hard as when taken from the bath, which should be raw linseed oil at a temperature of about 60 degrees Fahr.

A careful study of the pack hardening method will help every one handling steel. It often makes possible the use of lower grade steels, and it enables pieces to be made of any desired shape with the knowledge that they can be hardened without cracking.

Case Hardening.

When wrought iron or machinery steel—especially the latter—will answer the purpose as well as tool steel, they are generally used. The first cost is less, and it can be machined much more cheaply, and in many cases it is better adapted to the purpose.

Machinery steel is made by two entirely different processes, namely: the Open Hearth and the Bessemer processes. Each method produces steel adapted to certain classes of work. There are many grades of steel made by each of these processes, these being determined by the amount of carbon or other elements present in the steel. Machinery steel is not only valuable to the manufacturer on account of its low first cost, as compared with tool steel, and the ease with which it may be worked to shape, but it possesses the quality of toughness, and is not so susceptible to crystallization from the action of shocks and blows. A very valuable feature is, that by subjecting it to certain processes, the surface may be made extremely hard, while the interior of the steel will be in its normal condition, thereby enabling it to resist frictional wear and yet possess the quality of toughness.

The hardening of surfaces of articles made of wrought iron and machinery steel is generally termed

"case hardening," and consists in first converting the surface of the article to steel, then hardening this steel surface. In order to convert the surface to steel, it is necessary to heat the piece red-hot, then treat it while hot with some substance which furnishes the necessary quality to cause the steel to harden when plunged in a cooling bath.

Most machine shops have some means whereby they can harden screws, nuts and similar articles. Where there is only a limited number of pieces to harden, it is customary to heat the work in a blacksmith's forge, in a gas jet, or in any place where a red heat can be given the piece. When hot, sprinkle with a little granulated cyanide of potassium, or some yellow prussiate of potash, or a mixture of prussiate of potash, sal ammoniac and salt. If cyanide of potassium is used, it is advisable to procure the chemically pure article, as much better results may be obtained. The reader should bear in mind that this is a violent poison. Re-heat to a red and plunge in clear, cold water. When there are large quantities of work to harden, this is an expensive as well as a very unsatisfactory way. To case harden properly, one must understand the material of which the article is made and the purpose for which it is to be used—whether it is simply to resist friction or wear, or to resist sharp or heavy blows, a bending or twisting strain, or whether it is merely desired to produce certain colors.

We will first consider the case hardening of work that simply needs a hard surface, with nothing else to be taken into consideration. Pack the articles in an iron box made for this purpose, as shown in Fig. 131. The size and shape of the box used depend, as a rule,

on what can be found in the shop. But when results are to be taken into consideration, it is advisable to procure boxes adapted to the pieces to be hardened. It is not policy to pack a number of small pieces, which do not require a deeply hardened portion, in a large box, especially if it is desirable to have a uniformity in the hardened product, as the pieces which

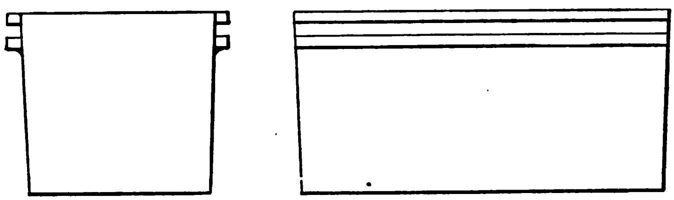


Figure 131. Box for case hardening.

are near the walls of the box will become red-hot long before those in the center. And as steel or iron absorbs carbon only when red-hot, the pieces nearest the outside would be hardened to a greater depth than those near the center of the box.

For small articles, where but a few pieces are to be hardened at a time, a piece of gas-pipe may be used. Screw a cap solidly on one end or plug the end with a piece of iron, using a pin to hold it in place. The outer end may be closed by means of a piece made in the form of a cap to go over the end, or it may be a loose-fitting plug held in place by a pin, as shown in Fig. 118. When a hardening box of the description shown in Fig. 131 is used, the heat may be gauged nicely by running test wires through the cover to bottom of tube, as shown in Fig. 126. Pack the pieces of work in a mixture of equal parts, by measure, of

granulated raw bone and granulated charcoal mixed thoroughly together. Cover the bottom of the hardening box to a depth of 1½ inches with the mixture, pack a row of work on this, being sure that the articles do not come within ¼ to ½ inch of each other, or within 1 inch of the walls of the box. Cover this with the packing material to a depth of half an inch.

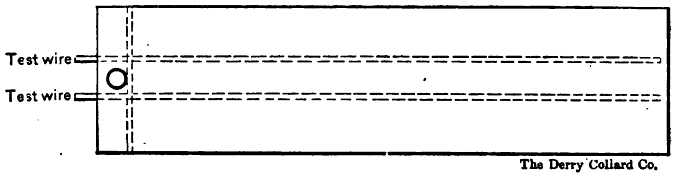


Figure 132. A method of using test wires.

Tamp down, put on another layer, and so continue until the box is filled to within 1 inch of the top. Fill the remaining space with refuse packing material left over from previous hardenings, if you have it. If not, fill with charcoal or packing material, tamp well, put on the cover, and lute the edges with fireclay to prevent as much as possible the escape of the gases. This is necessary, as the carbon is given off from the packing material in the form of a gas. Then again, if there are any openings, the direct heat will penetrate these and act on the work in a manner that gives unsatisfactory results.

If the articles are so large that they would not cool below a red heat before reaching the bottom of the bath, they should be wired, as shown in Fig. 130, before put-

ting in the hardening box. Use *iron* binding wire, sufficiently strong to hold the piece when it is worked around in the bath. If the articles are too heavy for wiring, we must devise some other way of holding—either tongs or grappling hooks. If the pieces are small, they can be dumped directly from the box into the tank, sifting the work out of the box somewhat slowly, so that the articles will not go into the bath in a body. If the tank is large enough, it is a good plan to have wires across from side to side, about 4 inches apart in horizontal rows. Have the rows 3 or 4 inches apart. Do not put any two consecutive rows of the wires underneath each other, but in such a manner that the work will strike the wires as it passes to the bottom of the tank. In striking these wires, the work will be separated, and any packing material adhering to it will be loosened by the jar. The work will also be turned over and over, thus presenting all sides to the cooling effects of the bath as it passes through. These wires can be arranged as shown in Fig. 133 by taking two pieces of sheet metal, a little shorter than the inside length of the tank, drilling holes in them as described in the arrangement of wires, and wires can be passed through these holes and riveted, thus making a

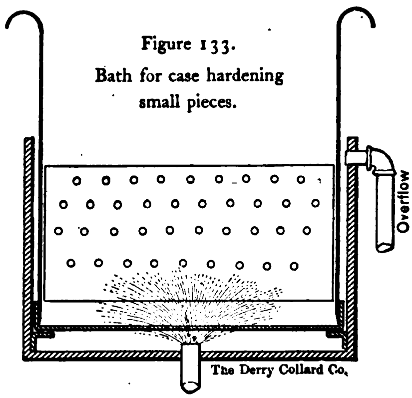


Figure 133.
Bath for case hardening small pieces.

permanent fixture that can be placed in the tank and taken out at will. The distance the wires are apart can be varied to accommodate the particular kind of work that is to be done. They must be far enough apart so that the work cannot become lodged on them.

This simple device does away with the liability of soft spots in pieces of work that are case hardened. Do not have any wires within 8 or 10 inches of the bottom of the tank. Have a coarse screen or a piece of sheet metal drilled full of holes somewhat smaller than the piece we are to harden. Block it up about 4 inches above the bottom, to allow a free circulation of water underneath it. This also allows the water to pass through it around the work, and the packing material will pass through it, giving the water a better chance to get at the work. The water inlet should be at the bottom of the tank, and we should have an outlet about 2 inches from the top to allow the surface water to escape. The cold water coming up from the inlet at the bottom should be turned on before we dump the work, allowing it to run until the work is cold. In heating the work, any form of furnace that will give the required heat and maintain it evenly for a sufficient length of time will do.

The cover of the boxes should have several ¼ inch holes drilled in the center, as shown in Fig. 26. After putting the cover in place, put pieces of $\frac{3}{16}$ inch wire through these holes down to the bottom of the boxes, allowing them to stick up an inch above the cover, to enable us to get hold of them with the tongs. The boxes may now be put in the fire, and subjected to a heat which should vary according to the character of the work. The work should be heated to a red, and

for some classes of work it may even be brought to a bright red. When it is thought that the work has been in the fire long enough to heat through, draw one of the wires with a long pair of tongs. If the wire is red the entire length, time from then. If not, wait a few minutes and draw another, and so on until one is drawn that is red the entire length.

The writer considers this the proper method to employ in timing all work being heated in the fire, whether it is to be annealed or case hardened, charging for hardening by the Harveyizing method, or when we are pack hardening tool steel. If the work is timed from the time it is put in the fire, the results will be uncertain, as the fire is hotter one day than it is another. Sometimes the fire acts dead, another day lively, so the box is longer in heating at one time than at another; but if it is timed from the period when the work commences to take carbon, the results will be as nearly uniform as it is possible to get them, provided the heat is uniform, which can be gauged quite closely by the eye. Better results can be obtained by the use of the pyrometer, although for ordinary work this is not necessary. After running the work the proper length of time, which varies according to the nature of the steel and the purpose for which it is intended (small articles, ¼ inch or less, which do not require anything but a hard surface, should be run one or two hours after they are red-hot), dump into the water.

If it is desired to have them colored somewhat, hold the box about a foot or 18 inches above the tank, allowing them to pass this distance through the air before striking the water. If we are hardening small screws having slots for screw-drivers, and are harden-

ing simply to keep the screw-driver from tearing the slot, we can use expended bone as packing material—*i. e.*, bone that has been used once before. It will make the work hard enough for all practical purposes, yet not hard enough to break. If we wish to harden deeper, we must run about five hours after the work is red. By running sixteen or twenty hours, we can harden to a depth of ⅛ inch. In the case of small articles, it is best to use a bone not coarser than what is known as No. 2 granulated raw bone. When we are to run for a long period of time in the oven, we should use a coarser grade.

When it is necessary to harden very deep, it is advisable to pack the work with coarse bone, letting it run from 15 to 20 hours in the fire, then taking out and repacking with fresh material. Work that is allowed to run for too long a time with the same packing material is very liable to be not only insufficiently carbonized, but to be in a measure decarbonized and highly charged with phosphorus, which is very injurious to the material we are using. The charcoal used in the mixture should, if possible, be the same size granules as the bone. The commercial article is much superior to anything we can pound and sift, so it is policy to buy it. The first cost may seem a trifle stiff, but if account is taken of the time it takes to pound and sift a barrel of charcoal, it will be found the cheaper article.

There are many special preparations used in case hardening, some of which are excellent for special work, while some are good for all kinds of work. When we wish to harden deep in a short space of time, it is advisable to use bone black in place of granulated raw bone. Bone black, or animal charcoal, as it is

commercially called, is prepared by burning bones in a special furnace. It comes in the form of a powder. It leaves a finer grain in the work hardened, and it will make it stronger than if hardened with raw bone. Another form of bone which gives excellent results is called hydrocarbonated bone, a form of bone black treated with oil so that it gives off its carbon more readily than either form mentioned before. It is not generally used, but for nice work it is very satisfactory.

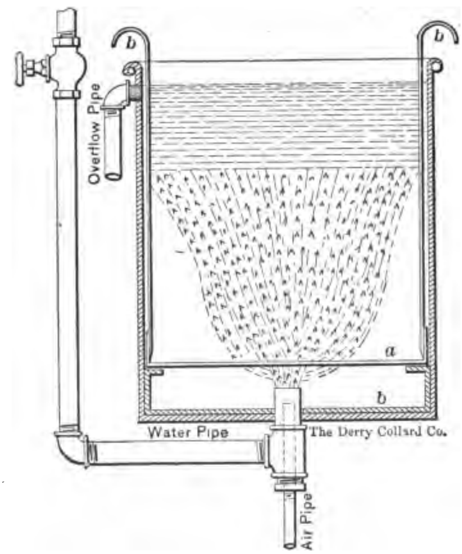


Figure 134. Bath having an air inlet with water, for obtaining colors.

If we wish to give a nice color to our work, it is necessary to first polish it and be sure it is clean when packed in the hardening box. Use the following mixture when packing:

10 parts No. 1 granulated raw bone.
2 parts bone black.
1 part granulated charred leather.

Mix thoroughly before using. The results will be much more gratifying, if a pipe which is connected with an air pump is run up into the water inlet pipe, as shown

in Fig. 134. By this means a jet of air is forced into the water at the bottom of the tank in such a manner that it will be distributed through the whole bath, in order that each piece of work may come in contact with it as the work passes through the water.

When articles are hardened by the first process mentioned, heating in the fire and treating with cyanide of potassium, very nice colors can be obtained by taking a piece of gas pipe, putting one end in the bath and blowing through it, passing the work through the air in the water when we dip it. When the articles are thin, and must be very hard, yet tough, it is best to use a bath of raw linseed oil.

If this bath is used, it is advisable to attach a piece of iron binding wire to each piece when we pack the work, allowing the wires to hang over the sides of the box. When we take the box from the fire, the articles can be removed from it and immersed in the oil by means of the wires. They should be worked around well in the bath until the red has disappeared, but in such a manner that broad sides are not moved against the cool oil, or the articles may spring. By taking this precaution, there will be no difficulty in obtaining satisfactory results in practically all cases.

The advent of the bicycle opened the eyes of mechanics to the fact that a low grade steel could be used to advantage for many purposes, where formerly it would have seemed necessary to use tool steel under similar conditions.

As competition made it necessary to produce a machine weighing less than one half of what it originally weighed, and capable of standing up under greater strain, methods were devised whereby low grade steel

could be hardened in a manner that insured its standing as well as if the article was made of the more costly tool steel.

Crank axles were made of 40-point carbon open hearth steel, which was given sufficient stiffness by heating red-hot and plunging in *hot* oil. When the percentage of carbon was lower than that mentioned—40-point—it was sometimes found necessary to pack the axles in a box with granulated wood charcoal, subjecting them to a red heat for a period of from 2 to 6 hours; they were then dipped in hot oil. If the percentage of carbon was too low to insure hardening by this process, they were packed in a box with equal parts of charred leather and charcoal, run for a sufficient length of time, and quenched as described.

It was found necessary to make handle bar binders very light. When made of tool steel, hardened and tempered, the cost was too great, and if made of ordinary machine steel, case hardened, they were elastic, but stretched when strain was put on them. By using a 30-point carbon steel packing in charcoal, and running 1 hour after they were red-hot, then plunged in hot oil, they gave as good satisfaction as though made of tool steel, while the cost of machining was not one-quarter as much.

Hardening bevel gears for bevel gear chainless bicycles caused a great many anxious moments in shops where it was attempted. One prominent manufacturing concern lost at one time 75 per cent. of all gears hardened, according to their own statement.

At the time mentioned the writer was connected with a concern manufacturing a high-grade chainless wheel. The gears were of the design represented in

Fig. 135. They were made of 40-point carbon open hearth steel, which was extremely low in phosphorus. When hardened, they were packed in a hardening box

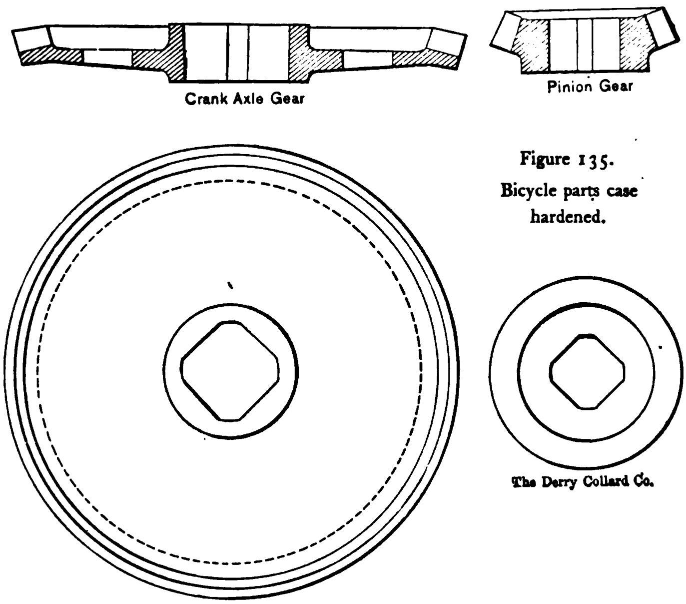


Figure 135.
Bicycle parts case hardened.

with a mixture of granulated charred leather and charcoal, run at a red heat for a sufficient length of time to make the teeth hard enough to resist wear, yet not brittle enough to break when in action. This was the reason it was necessary to use a steel of a very low percentage of phosphorus.

The crank axle gear, as shown above, was run 1¾ hours after it was red-hot, then dipped in a bath of raw linseed oil at a temperature of 100 degrees Fahr.

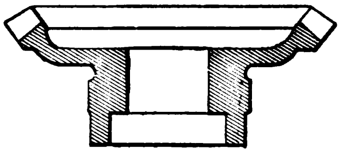
The surfaces of the teeth were extremely hard; the gear, being made light to reduce weight, necessarily had to be very stiff, yet tough. They gave the best of satisfaction. Another concern in the same line of business packed their gears in granulated raw bone, with the result they were so brittle it was found impossible to use them. Still another packed their gears in raw bone, run them for one hour after they were red-hot, then allowed them to cool, reheated and hardened. The gears were so brittle the teeth would break when the surfaces were not sufficiently hard to resist wear. Both concerns adopted the method in use in our factory and had excellent results.

While bone is an excellent hardening agent, it is not good practice to pack steel in it for case hardening, if brittleness is objectionable in the hardened product, because, as previously stated, raw bone contains phosphorus, and phosphorus when present in steel, especially in combination with carbon, causes the steel to be brittle.

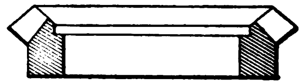
The pinion gear, shown in Fig. 135 on preceding page, was hardened in the same manner as the one mentioned, with the exception of the temperature of the bath, which was about 60 degrees. When hardening the small gears, it was found possible to wire several on the same wire, being careful to have sufficient space between them to insure good results. The advantage of this method of wiring was that a great amount of time was saved when dipping in the bath. While it was necessary to dip the large gear in the bath in a vertical position, working it up and down, the small gears were dipped in any position, as their shape prevented their springing.

Case hardening small screws.

The gears, shown in Fig. 136, were used on the rear end of the gear shaft and rear hub, and were hardened in the same manner as the crank axle gear.

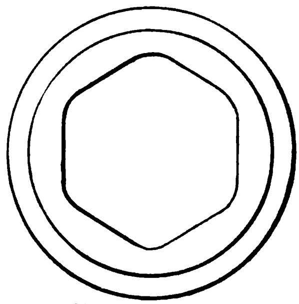


Gear Shaft Rear End Gear



Hub Gear

Figure 136. Bicycle parts case hardened.



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While the critic might claim that some of the examples given do not properly belong under the head of case hardening, it has seemed advisable to group them under this head, because they are, as a rule, so classified in most shops.

It is generally advisable when case hardening screws made of Bessemer steel wire, to pack in *expended* bone. In this way the extreme brittleness incident to the use of raw bone is done away with in a great measure. The writer has seen batches of small screws ($\frac{3}{16}$ inch and under) made of Bessemer screw stock, which was packed in raw bone and hardened, so brittle that they would break from the necessary power applied to a screw-driver to screw them into the hole. At the same time, when annealed, they filed easier, and were apparently softer than a piece of the rod they were made from. They had been heated to the different temper colors in order to toughen them, but it did no

good. They were so brittle, even when annealed, that they were useless.

Yet screws made from stock out of the same batch, packed in *expended* bone and run for the same length of time, were apparently all right. Had charred leather been used, it would have made them tougher, but the expended bone made them tough enough for all practical purposes. As it is much cheaper and more readily obtained, it is generally used for work of this class.

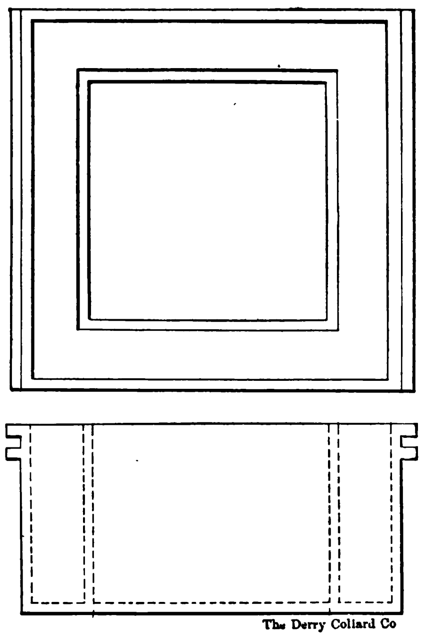


Fig. 137. Another form of box for case hardening.

When case hardening small pieces, which do not require a deeply hardened portion, but which must be uniform, as bicycle chain links, it is advisable to use boxes made especially for them, in order that all the pieces in the box may become heated at about the same time. The writer has in mind a certain stock used for making bicycle chain block links, which was packed in a box of the de-

scription shown in Fig. 137, using as packing mixture equal parts animal charcoal, wood charcoal and charred leather. The work was run 45 minutes after it became red-hot, then dumped in cold water, and gave excellent results. The links tested showed up well, and the chains gave the best of satisfaction when on the wheels. A different stock was procured, and it was found by experiment that links made from the new stock could be run only 25 minutes after they became red-hot. If run the same length of time as those made of the first stock used, they would break very easily, but when run only 25 minutes gave very good satisfaction.

In many shops it is customary to make snap gauges of machine steel. They are much easier made, the cost of material is less, and, if hardened properly, they will wear well. It is best, in cases of this kind, to use open hearth steel rather than Bessemer, as the latter runs more uneven. The best results will be obtained if we use as packing material granulated leather instead of bone. When packing, mix with an equal amount of granulated charcoal, run five or six hours, if the gauge is ¼ inch thick or more. Run at a very low heat, and dip in the oil bath. It will be found to be very hard, and probably straight. If hardening small pieces, it is advisable to use smaller boxes than when large pieces are being treated, as it takes some time to heat a large box through. Pieces near the walls of the box will become hot quicker than those in the center, and consequently will be hardened deeper.

Many pieces of work are made of tool steel when machine steel would answer the purpose as well, or better, were it not for the coarseness of the grain when

the piece is case hardened. The fine grain may be necessary to resist pressure and wear on some small part of the surface, or possibly it is to be subjected to the action of blows, and the grain being coarse, the surface has no backing and is soon crushed in. The causes of the open grain are: first, that it is the natural condition of the stock; second, the pores are open when heated, and the steel is absorbing carbon. The higher the heat to which the pieces are subjected, the coarser the grain.

It is possible to heat machine steel in such a manner as to produce a fine grain—in fact, as fine as that of the nicest tool steel. While the writer would not be understood as advocating the use of machinery steel in the making of nice tools, as so good an article cannot be produced as if made of tool steel, yet for certain purposes cutting tools are made of a good grade of open hearth steel, case hardened very deep, with fine compact grain, which gives excellent results. This is particularly the case where the cutting part is stubby and strong. Cams made of low grade steel, and hardened by this method, will resist wear as well as though made of tool steel and hardened, and they are not as liable to flake off or break. Punch press dies that are to be used for light work, cutting soft metals where there are no projections, will do very satisfactory work. Gauges, whether they be snap, plug, ring or receiving, are hardened with much less liability of their going out of shape, are easier to make, and will wear as long as though made of tool steel. Then, too, the necessity of allowing them to "age" after hardening, before grinding to size, as is the case when gauges are made of tool steel for accurate work, is done away with.

What is needed in case hardening.

Many bicycle parts, formerly made of a good grade of tool steel, are now made of machine steel, and the best of results are obtained. Such is not apt to be the case if they are simply case hardened by the ordinary method, as the grain is too coarse to resist the peculiar action of the balls, particularly on the cones and ball seats. Spindles of machines, where there is considerable tendency to wear, also a pounding or twisting motion to resist, where tool steel would be liable to break and ordinary case hardening would yield to such an extent as to make the bearings out of round, can be treated very successfully by this method.

All that is needed is a good hardening furnace, large enough to receive as many boxes as we may need, a plentiful supply of boxes, some granulated raw bone, a good supply of charcoal and a small amount of hydro-carbonated bone, and some charred leather for our nicest work. We should also have a suitable supply of water in a large tank, and a smaller tank arranged so that we can heat it to any desired temperature, and a bath containing raw linseed oil. The work should be packed in the hardening boxes as for ordinary case hardening, run about the same length of time, and left in the oven to cool the same as for annealing.

When cool, the articles may be heated in the open fire, muffle furnace or in the lead crucible, and hardened the same as tool steel; or, if the articles are small, and there are many of them, they can be re-packed in the hardening box with charcoal. But do not use any carbonizing substance, as that would have a tendency to open the grain, and the object of the second heat is to close the grain. The lower the hardening heat, the more compact the grain will be, as is

the case with tool steel. This method not only gives a close grain, but a very strong, tough surface, and, the center being soft, the piece is very strong.

When hardening tools whose office it is to cut metals, it is always best to use a packing mixture of equal parts of charred leather and charcoal. The kernels should be fine and of about the same size, if possible, for if the kernels of the leather were large, and those of the charcoal were small, the tendency would be for the finer to sift to the bottom of the box. Leather gives a stronger, tougher effect than bone, it being practically free from phosphorus, while bone contains a large percentage. The presence of phosphorus in steel makes it brittle, especially when combined with carbon. Yet for most purposes where there are no cutting edges bone works very satisfactorily in connection with machinery steel, and is much cheaper than leather. When using either bone or leather, mix with an equal quantity (by measure) of granulated charcoal. Being well mixed, the particles of charcoal keep the kernels of bone or leather from adhering to each other and forming a solid mass when heated. Then again, the charcoal has a tendency to convey the heat through the box much more quickly than would be the case were it not used.

If small pieces are to be hardened that do not need carbonizing more than $\frac{1}{32}$ of an inch deep, it is best to use No. 2 granulated raw bone. If the pieces require a very deep hardened section, it will need a coarser grade, as they must run longer in the fire. When hardening bicycle cones and similar articles, where it is necessary to carbonize quite deeply, it is best to pack with No. 3 bone and charcoal, equal parts, or better

yet, with two parts raw bone, two parts charcoal and one part bone black or animal charcoal. Pack in the hardening box, as previously described, run in the furnace 10 hours after the box is heated through, using the test wires to determine the beginning of the heat. After the work is cold, it can be reheated as described and hardened. It is advisable to occasionally break a piece of work and examine the grain, noticing how deep the hardening has penetrated. If not deep enough,

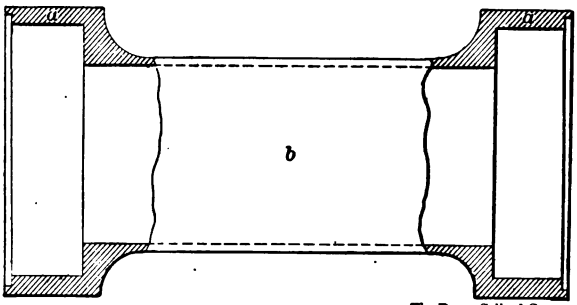


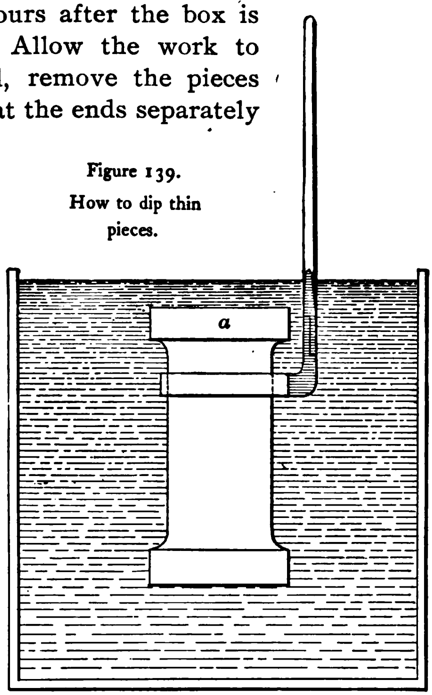
Figure 138. Piece to be hardened, leaving the center soft.

repack in the boxes with fresh material, and run again; but if directions given are followed closely, results will in all probability be found satisfactory. The grain, as far in as the carbon has penetrated, should be as fine as that of hardened tool steel.

In hardening thin pieces, where it is necessary to resist wear or blows, it is advisable to use leather as a packing material, hardening in a bath of raw linseed oil. The pieces will be found extremely tough and hard. It is sometimes desirable to harden the ends of a piece of work, leaving the center soft. Take, for instance, the piece shown in Fig. 138. The surface of the

ends marked *a* needs hardening, while the portions marked *b* should be soft. Pack the ends inside and out with hydrocarbonated bone and charcoal, having previously filled the center with expended bone. Cover the outside of the center with expended bone, run in the oven 7 or 8 hours after the box is heated through. Allow the work to cool as described, remove the pieces from the box, heat the ends separately in the lead crucible, dip in a bath of lukewarm water, dipping with the heated end *a* up, as shown in Fig. 139. Otherwise the steam generated from contact of the hot steel with water would prevent the water from entering the end where it dipped with the heated end down. If the water cannot enter the work and get at the portions necessary to be hard, they certainly will not harden. If the piece is dipped with the heated end as described, the water readily enters. The ends will be found extremely hard, and the grain will be very compact. Not only is this so,

Figure 139.
How to dip thin pieces.



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but the piece will be much less liable to crack than if the extreme ends were dipped first and hardened, as would be the case with the heated end down.

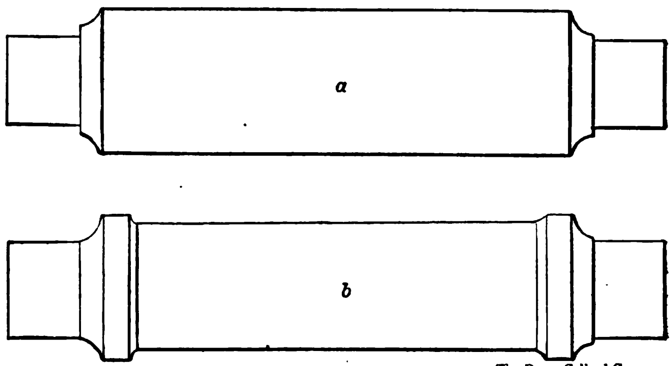


Figure 140. Bicycle axle.

Another method employed when hardening the ends of a piece of work and leaving the center soft, can be illustrated by the bicycle axle shown in Fig. 140. The ends are machined to shape, the center being left large, as represented at *a*. The axle is packed in the hardening box and charged with carbon, as described. The center is then cut below the depth of charging shown at *b*. The piece is ready for hardening. This can be accomplished by heating in an open fire, muffle furnace or lead crucible, and dipping in the bath.

When it is necessary to harden the center of a piece and leave the ends soft, it can easily be accomplished. If the ends are to be smaller than the center,

the pieces may be packed in the hardening box with raw bone and charcoal. Run for a sufficient length of time to carbonize to the desired depth of hardening. Allow the pieces to cool off. When cool, machine the ends, as shown by lower cut in Fig. 141, the upper cut

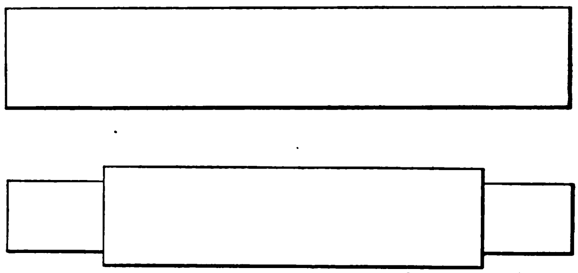


Figure 141. Method of treatment for chain studs.

representing the piece of work before charging with carbon; the lower, after machining the carbonized portions at the ends. It may now be heated red-hot and dipped in the hardening bath in the usual manner. The center will be found hard.

A method employed in making bicycle chain studs that are hard in the center at the point of contact with the block link and soft on the ends, in order that they may be readily riveted in the side links, consists in taking screw wire or special stud wire of the desired size, packing it in long boxes with raw bone and charcoal and running 3 or 4 hours after it is red-hot. Then allow it to cool off. The stock is now placed in the screw machine and cut to shape—that is, the ends are cut down to proper size. The center, being of the proper size, is not machined. The studs may be heated

in a tube in any form of fire and dumped in a bath of water or brine. The center will be hard enough to resist wear, while the ends will be soft, the carbonized portion having been removed.

An interesting experiment can be tried, which in itself is of no particular value, except that it acquaints

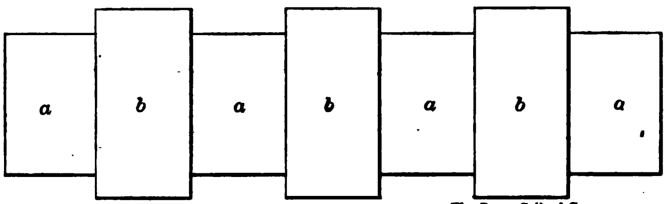


Figure 142. An interesting experiment.

one with the manner in which carbon is absorbed by steel. Take a piece of open hearth machinery steel, turn it in the lathe to the shape shown in Fig. 142, necking in every half inch to the depth of ⅛ inch, leaving the intervening spaces ½ inch long. Pack the piece in the hardening box with raw bone and charcoal. Run five or six hours after the box is heated through. When cold, turn the shoulders marked *b* to the size of *a*, leaving *a* the same size as before charging. Heat to a low red and dip in the bath. The portions marked *a* will be found hard, while the balance of the piece will be soft.

When pieces are to be case hardened, and it is considered desirable to leave a certain portion soft, it is accomplished many times by making tongs of the proper form to effectually prevent the contents of the hardening bath coming in contact with the portion men-

tioned Suppose, for example, a piece of the design shown in Fig. 143 is to be case hardened, and it is de-

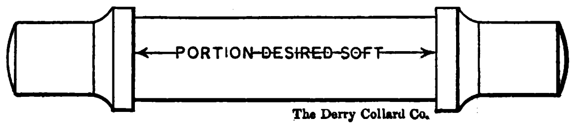


Figure 143. Piece with portion desired soft.

sired to leave the central portion marked soft. Make a pair of tongs to grasp the piece, as shown in Fig. 144. It will be seen that the portion mentioned is effectually protected by the tongs. The piece may be dipped in the bath, and worked around well until the red has disappeared, when it may be dropped to the bottom of the tank and left until cold. When it is desirable to leave a portion of an article

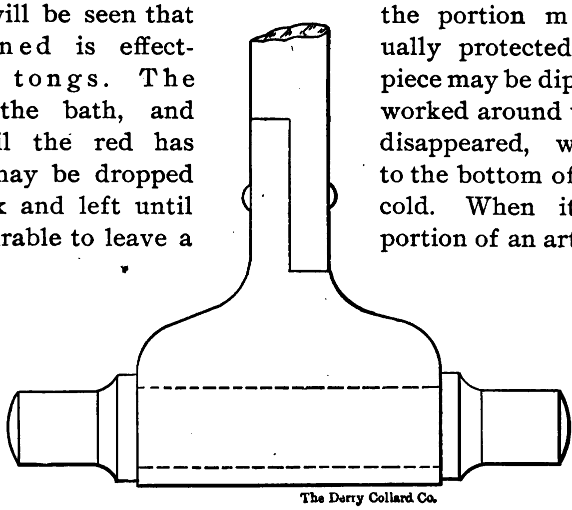


Figure 144. Tongs for handling piece shown above.

soft, as shown in Fig. 145, it is sometimes accomplished by covering the portion to be soft with fire-clay, as shown in lower view. The fire-clay may be held in place by means of iron binding wire; sometimes the fire-clay is held in place by means of plasterers' hair,

which is worked into the mass when it is mixed with water. The fire-clay prevents the carbon coming in contact with the stock where it is desired soft.

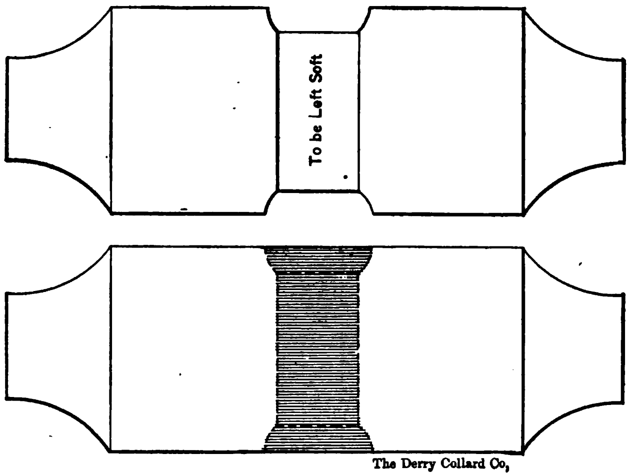


Figure 145. The use of fire-clay for soft spots.

A method employed in some shops consists in wrapping a piece of sheet iron around the article over the portion desired soft, as shown in Fig. 146. The sheet metal is held in place by means of iron binding wire, as shown.

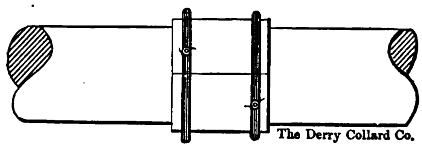


Figure 146. Using sheet iron to prevent hardening.

A very common method, which is costly when many pieces are to be treated, consists in forcing a

collar on to the piece over the portion desired soft, as shown in Fig. 147. The collar is removed after the article is hardened.

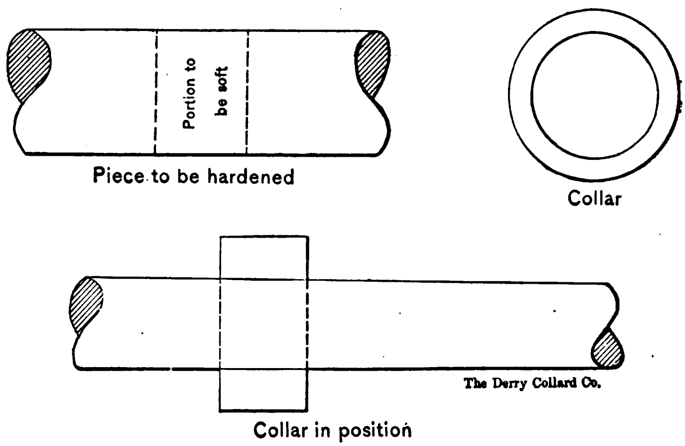


Figure 147. A collar for keeping portions soft.

When machine nuts are to be case hardened, and for any reason it is desirable to have the interior threaded portion soft, it is accomplished by screwing a threaded piece of stock in the hole before the nuts are packed in the hardening box.

As carbon can not penetrate a nickeled surface, articles are sometimes nickel-plated at portions desired soft; this, however, is, generally speaking, a costly method of accomplishing the desired result.

It is sometimes considered necessary to harden the

surfaces of pieces quite hard and leave the balance of the stock stiffer than would be the case where ordinary machinery steel is used. In such cases many times an open hearth steel is selected, which contains sufficient carbon, so that it will become very stiff when quenched in oil. The writer has in mind a gun frame which, on account of the usage to which it was to be put, must have a hard surface, while the frame itself must be very stiff. They were packed in a mixture of charred leather and charcoal, placed in the furnace and run for a period of 1½ hours after they were red-hot. They were then quenched in a bath of sperm oil. The stock used was 30-point carbon open hearth steel. Were the articles heavier or a greater degree of stiffness desirable, a steel could be procured having a greater percentage of carbon.

When toughness or strength is wanted in the case hardened product, a steel having much phosphorus should not be used; in fact, the percentage of phosphorus should be the lowest possible, as steel containing phosphorus, in connection with carbon, is extremely brittle. For this reason, articles which must be extremely tough should not be packed in raw bone, as this contains a very high percentage of phosphorus.

At times a job will be brought around to be case hardened, and one particular part will be wanted quite hard, while the balance of the piece will not require hardening very hard or deep. In such cases, if the portion mentioned be a depression, it may be placed uppermost in the hardening box, and some prussiate of potash or a small amount of cyanide of potash placed at this point, the piece being packed in granulated raw bone or leather, and run in the furnace a short time.

The article may be quenched in the usual manner. The portion where the potash was placed will be extra hard.

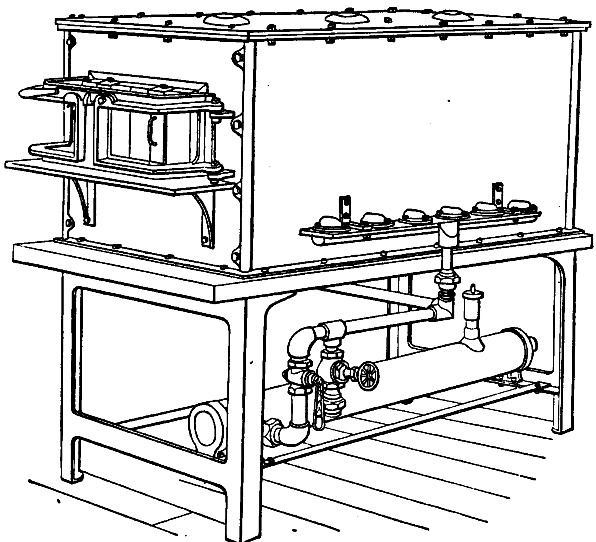


Figure 148. Gas furnace for case hardening.

The furnace used in case hardening should receive more consideration than is many times the case; an even heat that can be maintained for a considerable length of time is essential if *best* results are desired.

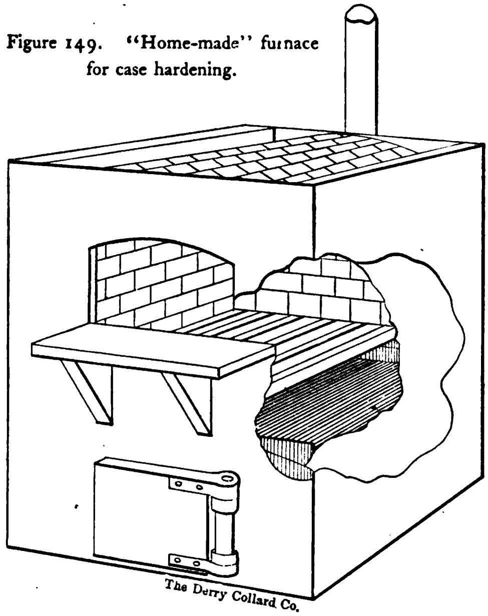
A very satisfactory form of furnace is represented in Fig. 148; it burns illuminating gas as fuel.

When it is considered desirable to use hard coal as

fuel, the furnace made by the Brown & Sharpe Co., of Providence, R. I., gives excellent results.

When it is considered advisable to construct on the

Figure 149. "Home-made" furnace for case hardening.



premises a furnace burning charcoal or coke, the form shown in Fig. 149 will be found very satisfactory.

However, the form and size of furnace depend in a great measure on the character and amount of work to be hardened.

Baths for Case Hardening.

The bath that is to be used for cooling work being case hardened must be suitable to the work being

hardened. Where work is case hardened in large quantities, it is customary in most shops to harden in iron boxes. When the work is in the proper condition, the box is inverted over a tank of water or some fluid, and the contents dumped into the bath. If the pieces of work are large or bulky, and the tank is shallow, they reach the bottom while red-hot, and, as a con sequence, the side of the piece that lays on the bottom will be soft. In order to overcome this trouble, the tank must be made deep enough so that the pieces will be sufficiently chilled before reaching the bottom. If it is not considered advisable to have an extremely deep tank and the pieces are large, various ways are taken to insure their hardening.

One method which the writer has used with excellent results is to have a series of rows of wire rods reaching across the tank, no two consecutive rows being in the same vertical plane, as mentioned in the previous section. The work as it descends into the bath strikes these wires, which turns them over and over, bringing all portions in contact with the contents of the bath. These wires also separate the pieces from each other and from any packing material which may have a tendency to stick to them. The wires also retard the progress of the articles, giving them more time to cool before reaching the bottom of the bath.

In order to insure good results, it is necessary to have a jet of water coming up from the bottom of the tank. An outlet is provided near the top for an overflow. The overflow pipe, of course, should be larger than the inlet pipe, and should be located far enough below the top edge of the tank, so that the contents will not overflow when a box of work is dumped into it.

Bath with catch pan.

In order to get the hardened pieces out of the bath easily, it is necessary to provide a catch pan, as shown in Fig. 150. The bottom of this pan should be made of strong wire netting or a piece of perforated sheet metal, preferably the former. The holes in the pan allow the packing material to fall through to the bottom of the tank, and also allow the water from the supply pipe to circulate freely around the work and to the top of the bath. This catch pan should be provided with strong wire handles, as shown, in order that it may be readily raised.

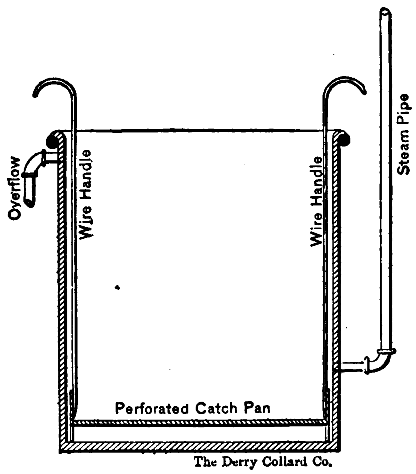


Figure 150. Case hardening bath with catch pan and steam pipe.

I was at one time requested to call at a shop where they were having very unsatisfactory results with their case hardening. An examination showed they were dumping their product into a barrel of water to harden. The box containing the work was inverted over this barrel, and the work and packing material went into the water in a lump. Some of the pieces that happened to get out of this mess were cooled sufficiently to harden somewhat, but the majority of the pieces were soft, or else they were hard on one side and soft on the

other. An examination of the bottom of the barrel showed it to be considerably charred. In places the outline of the pieces was plainly visible. These pieces had reached the bottom red-hot, and had burned their way into the wood. It is needless to say that the side of the piece of work which was down did not harden.

As those in charge of the work did not think it advisable, considering the limited amount which they had to case harden, to get a tank of the description shown in Fig. 150, we made a catch pan as described, blocked it up about 6 inches from the bottom of the barrel by means of bricks. We then bored a hole into the bottom of the barrel, screwed in a piece of pipe, and by this means were able to connect an ordinary garden hose, so as to get a jet of water coming up from the bottom. As the barrel was out of doors, we simply bored a two-inch hole about two inches from the top of the barrel for an overflow, and let the water run on the ground. When the work was ready to dump, we sifted it out of the box into the water gradually, rather than to dump it in a body. As soon as the box was emptied, we grasped the wire connected with the catch pan, and raised and lowered the pan in a violent manner, in order to separate any pieces that might have lodged together. The result was very satisfactory, and I think they are still using that barrel.

Baths are made, when large quantities of work are hardened, with some means of keeping the work in motion after it reaches the bottom of the bath. This is sometimes done by mechanically raising and lowering the catch pan, and at the same time turning it around. Then again, it is done by means of several sweeps, which are attached to the lower end of a verti-

cal shaft, the shaft resting in a bearing in the center of the catch pan. These sweeps, or arms, revolving, keep the pieces in motion, turning them constantly, but unless arranged properly, they have a tendency to gather the work in batches, thereby acting exactly opposite from what they are intended to do. Then again, they have a tendency to scratch the surface of the work, which is a serious objection, if color work is wanted. When it is desirable to get nice colors on case hardened work, an air pump may be connected with the bath, as shown in Fig. 134, the water and air entering the bath together. While it is not advisable to let air come in contact with the pieces to be hardened for colors while passing from the box to the water, yet the presence of air in the water would have the effect of coloring the work nicely.

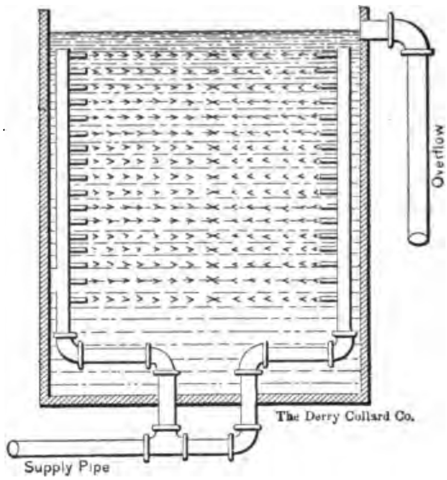


Figure 151. Bath for cooling slender case hardened articles.

When hardening long slender articles or those liable to give trouble if a bath of the ordinary description is used, excellent results may be obtained by the use of a bath with perforated pipes extending up the sides of the tank, as shown in Fig. 151.

Spring Tempering.

When it is necessary to give articles made of steel a sufficient degree of toughness, in order that when bent they will return to their original shape, it is accomplished by a method known as spring tempering.

The piece is first hardened, then the brittleness is reduced by tempering until the article, when sprung, will return to its original shape.

Generally speaking, it is not advisable to quench pieces that are to be spring tempered in cold water, as it would not be possible to reduce the brittleness sufficiently to allow the piece to spring the desired amount without drawing the temper so much that the piece would set. Steel heated red-hot and plunged in oil is much tougher than if plunged in water; and as toughness is the desired quality in springs, it is advisable to harden in oil whenever this will give the required result.

For many purposes a grade of steel made especially for springs gives better results than tool steel; for instance, bicycle cranks made of a 40-point carbon open hearth steel will temper in a manner that allows them to stand more strain than if made of the finest tool steel, and the stock does not cost more than one-quarter the price of tool steel.

When springs are to be made for a certain purpose,

it is generally safer to state the requirements of the spring to some reliable steel maker, allowing him to furnish the stock best suited for the purpose, than to attempt to specify the exact quality wanted—unless, of course, the operator or manufacturer has, either by experience or by study, acquired the knowledge necessary to qualify him to judge as to the quality needed.

As previously stated, the hotter a piece of steel is heated for hardening the more open the grain becomes; and as hardened steel is strongest when hardened at the refining heat, it is always advisable to heat no hotter than is necessary to accomplish the desired result. But as springs are generally made of a steel lower in carbon than ordinary tool steel, and as low carbon steel requires a higher heat to harden than is the case when tool steel is used, it is necessary to experiment when a new brand of steel is procured, in order to ascertain the proper temperature in order to produce the best results.

When steel is heated to the proper degree, it may be plunged in a bath of oil or tallow and hardened, the character of the bath depending on the size of the piece to be hardened and the nature of the stock used. For ordinary purposes a bath of sperm oil answers nicely. In some cases tallow will be found to answer the purpose better. It is necessary sometimes to add certain ingredients to the bath in order to get the required degree of hardness.

The following is used by a concern when hardening clock springs: To a barrel of oil add 10 quarts of resin and 13 quarts of tallow. If the springs are too hard, more tallow is added. If, however, the fracture indicates granulation of the steel rather than excessive

hardness, a piece of yellow bees'-wax of about twice the size of a man's fist is added to the above.

The following mixture has been used by the writer with success in hardening springs which, on account of the thickness of the stock or a low percentage of carbon, would not harden in sperm oil:

Spermaceti oil	48	parts.
Neat's foot oil	46	"
Rendered beef suet	5	"
Resin	1	"

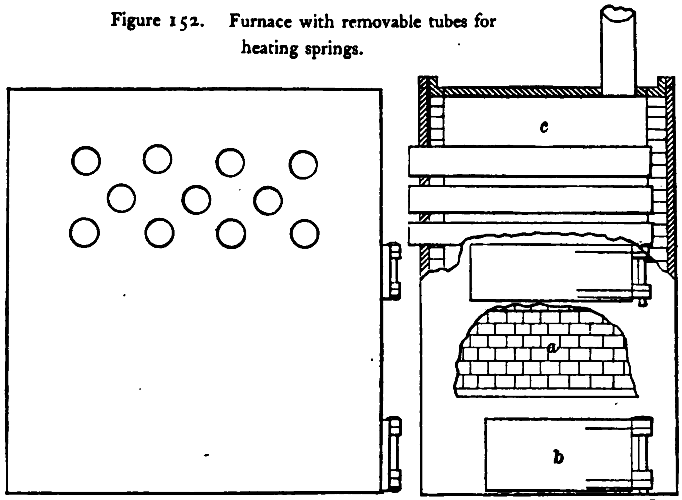
The proportion of the different ingredients may be changed to meet the requirements of the particular job. Resin is added to the oil to strike the scale. As the scale or oxidized surface of the steel, when subjected to heat, is liable to raise in the form of blisters, and as these are filled with gas, the contents of the bath can not act readily on the steel. A small proportion of spirits of turpentine is sometimes added to the oil for the same purpose, but as it is extremely inflammable, it is somewhat dangerous to use unless great care is observed. The presence of resin in a hardening bath has a tendency to crystallize the steel, and on this account is sometimes objectionable.

A very good method, when neither resin nor turpentine are used to strike the scale, consists in having a dish of soft soap; or, if that can not be procured, dissolve some potash in water, dipping the steel into this before heating. It has the effect of preventing oxidation of the surfaces, and helps to strike any scale that may have been on the stock previous to hardening.

When small springs are to be hardened, which, on account of their size, cool quickly, they can. if there are many of them, be placed in tubes and heated in a

furnace of the description shown in Fig. 152. When the pieces are heated to the proper temperature, a tube is removed and inverted over a bath. The contents should go into the bath in a manner that insures uniform results, that is, the pieces should be scattered in the bath. If the tube was held in the position shown

Figure 152. Furnace with removable tubes for heating springs.



at *a*, in Fig. 153, the pieces would go into the bath in a lump; but if it were held as shown at *b*, the pieces would become scattered, thus insuring good results.

When springs larger than those previously considered are to be hardened, an oven having some means of heating the articles in a manner that keeps them from coming in contact with the products of combustion should be used. Any form of a muffle having

sufficient capacity will do, or the pieces may be placed in a hardening box, having ½ inch powdered charcoal in the bottom, and a cover placed on the box—which need not be sealed. The box may then be placed in a furnace and subjected to heat. The cover may be raised from time to time and the contents of the box noted. This makes an excellent way of heating large coil springs and similar articles.

If the oven is sufficiently large, several boxes may be heated at a time. When a spring shows the proper temperature, which should be uniform throughout, it may be removed, placed on a bent wire and immersed in a bath of sperm oil, having a jet of oil coming up from the bottom, as shown in Fig. 154, A representing the outer tank containing water, B the bath of oil, C the pump used in drawing the heated oil from the bath through the pipe D; it is then forced through the coil of pipe in the water and back into the bath through the inlet E. F is the catch pan. The jet of

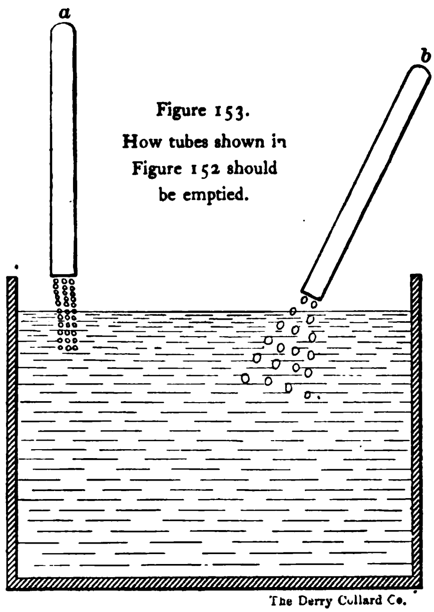


Figure 153.
How tubes shown in Figure 152 should be emptied.

oil is forced toward the top of the tank, as shown at G. The spring should be worked up and down in the bath until all trace of red has disappeared, when it may be lowered to the bottom of the tank and left until the temperature has been reduced to that of the contents of the tank, or until a convenient time comes for their removal.

As previously explained, it is not advisable to remove articles being quenched from the bath until they

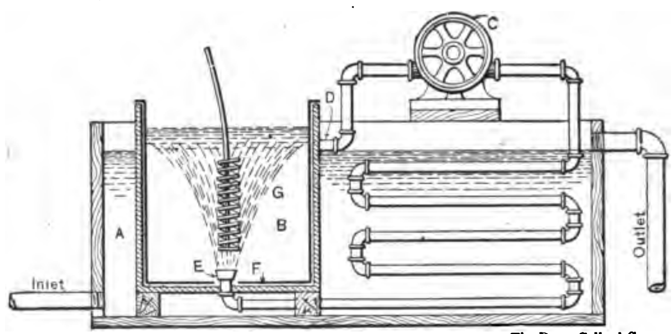


Figure 154. Oil bath for spring tempering.

are of a uniform temperature throughout. While this procedure might not make as much difference with a piece of work hardened in oil as one hardened in water, yet it is not a good plan to remove articles from the bath until they are reduced *throughout* to the temperature of the bath.

In order that the contents of the bath may be kept a uniform temperature, the pump shown in accompanying cut may be connected with the tank, as represented, the oil to be taken from near the top and pumped

through the coils of pipe in the outer tank, which should be supplied with running water.

When steel contains carbon of too low a percentage to harden properly in oil or any of the mixtures mentioned, the writer has used a bath of water at, or nearly at, the boiling point (212°) with very gratifying results. It may be found necessary with certain steels to reduce the temperature of the water somewhat.

Various methods are employed when drawing the temper. The one more commonly used than any other is to heat the spring until the oil adhering to the surface catches fire and continues to burn, when the piece is removed from the fire, burning until all the oil has been consumed. If this method is used, it will be found necessary to provide some means whereby a uniform heat may be obtained, or one part of the spring will be found to be too soft by the time the balance is rightly tempered.

If the spring is of heavy stock, it is necessary to burn the oil off three and sometimes more times, in order to bring it to the proper degree of elasticity. The process of drawing the temper by heating the spring until the oil catches fire from the heat contained in the steel is familiarly known as "flashing." Hardeners say that it is necessary to flash oil off this spring three times, or it is necessary to flash tallow off this spring twice, some using the oil the piece was quenched in, while others prefer some other kind of oil or tallow.

Springs hardened in boiling water may be coated with oil or tallow and the temper drawn as described, if it be found necessary. It is not policy to use a fire having a forced draft or blast when drawing articles to a spring temper. An open fire burning wood or

charcoal gives excellent results. A gas flame having no air blast also works very satisfactorily.

Springs of unequal sizes on the various portions require a very skillful operator, in order to get uniform results, if the above method is used. The thinner portions, heating faster than the heavier parts, become too soft before the other parts are soft enough. Consequently, it is advisable to temper these by a different method. The spring may be placed in a perforated pail, which in turn is set into a kettle of oil or tallow. This kettle is placed where a sufficient amount of heat may be obtained to draw the temper to the proper degree.

The amount of heat given is gauged by a thermometer, and varies according to the nature of the steel and the character of the spring. It ranges from 560° to 630°. The exact amount of heat necessary must be ascertained by experiment. This method furnishes a very reliable way of tempering all kinds of springs. The kettle should be so arranged that a cover may easily be placed on it in case the oil catches fire, as otherwise the operator, or the building, might be burned, or the work in the oil spoiled, or the thermometer cracked. The cover should be made high enough to take in the thermometer.

The cover should be provided with a long handle, in order that the operator may not be burned when putting it on the kettle. If it is not considered necessary to provide the cover mentioned, a piece of heavy sacking should be kept conveniently near for use. If this is placed over the top of the kettle, it will generally extinguish the flames.

The thermometer should not be taken from the hot

oil and placed where any current of air can strike it, or the glass will crack. It is advisable to leave it in the oil, letting it cool down with it. If the furnace where the oil is being heated is located where any current of air will strike the thermometer, it must be protected in some manner, or it will crack.

If it is considered advisable to remove the pail of work from the oil before the pieces are cool, it may be done, and the pieces dumped into a wooden box, covering the opening, so that the air will not strike the pieces. The pail may now be filled with fresh pieces requiring tempering. The pail of work should be placed in the kettle of oil. The kettle should not be placed in the fire again until the pieces of work have absorbed considerable of the heat that was in the oil, when the kettle may be placed in the fire and the operation repeated.

When work is hardened in large quantities, it is generally considered advisable to devise methods that allow of handling the work cheaply, at the same time keeping the quality up to the standard. Watch springs are sometimes heated in a crucible containing melted cyanide of potassium or salt and cyanide of potassium heated to the proper degree. The springs are immersed in the mixture until uniformly heated, then quenched. It is stated, however, that this mixture will not do when heating the hair springs, as it causes the nature of the steel to change slightly. These springs are heated for hardening in a crucible of melted glass.

When a make of steel is found that gives satisfactory results when made into springs and tempered, it is folly to exchange it for another make, unless convinced

that the other is better. A saving of a few cents, or even dollars, on an order of steel is quite often very costly economy, as many times springs do not give out until in actual use, and in that case they are oftentimes many miles from the factory where they were made.

When large numbers of springs that must receive severe usage are made, it is advisable to give them a test—at least, test an occasional spring. Give them a test somewhat more severe than they will be liable to get in actual use. By so doing it is possible to detect an improper method of hardening or tempering before the whole batch is done.

"Second Blue."

When all springs were made of tool steel and hardened, and the temper drawn one at a time, it was customary with some hardeners to draw the temper to what is known as the "second blue." After hardening, the springs were polished, then placed in a pan of sand and held over the fire until the temper colors commenced to show, the pan in the meantime being shaken to keep the sand and springs in motion and insure uniform heating. The tempers will show in order as set forth in the color table given under Drawing the Temper. After the colors had all appeared, the surface of the steel assumes a grayish appearance. When heated a trifle above this, it assumes a blue color again, which is known as the "second blue." When this color appears, the spring should be dropped in a tank of *hot* oil, leaving it to cool off with the oil.

Colors for springs—how obtained.

Another method sometimes used when drawing the temper of heavy springs made from high carbon steel consists in heating the article until sawdust dropped on it catches fire, or a fine shaving left from a hardwood stick, such as a hammer handle, being drawn across a corner of it, catches fire at the proper tempering heat.

Mechanics are sometimes surprised when they observe a spring in some conspicuous place which is drawn to a straw color, a brown or a light blue. It does not seem possible to them that a spring drawn to the temper represented by the color visible should be able to stand up to the work. The temper color shown is simply for appearance. The articles are first hardened and tempered to give them the necessary elasticity. This is ordinarily done by heating in a kettle of oil, gauging the heat with a thermometer. After heating to the proper temperature and cooling, they are polished. Any desired color can be given by placing the articles in a pan of sand and shaking over a fire until the desired color shows, when they may be dumped in warm oil to prevent running. This second operation does not affect the hardness or elasticity, provided they were not heated as hot as when the temper was drawn.

Many times it is impossible to harden and temper a spring in a manner that gives satisfactory results, because the spring was bent to shape when cold. Now, it is possible to bend most steel somewhat when cold, and yet have it take a good spring temper; but it is impossible to bend it beyond a certain amount, which varies with the steel.

The writer has seen large safety valve coil springs

rendered unfit for use by coiling when cold. If a piece of the same steel was heated red-hot and coiled, excellent results were obtained.

Many times it is necessary to anneal steel one or more times between operations in order to obtain good results. It was found necessary to anneal the spring shown in Fig. 155 after punching the blank and before bending at all. The first operation of bending brought the spring nearly to shape; it was then annealed, and the finishing operation taken. If it was bent to shape without annealing the second time, it would break in the corners when in use, if not in the operations of bending.

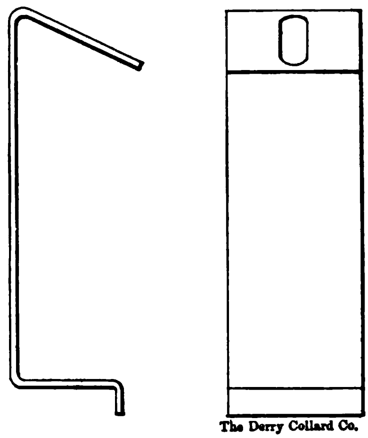


Figure 155. A peculiar case.

When annealing *sheet steel*, whether it be for springs or cutting tools, the utmost caution should be exercised. If the steel is allowed to stay in a red-hot condition for too great a length of time, the stock is rendered unfit for hardening. If heated red-hot and laid aside to cool *slowly*, much better results will follow than if it were packed in an annealing box with charcoal and kept red-hot for a considerable length of time. These long heats apparently have the effect of throwing the carbon out of its proper combination with the iron. It will harden, but can never be made elastic or strong.

Making Tools of Machine Steel.

While it is considered advisable in most shops to make articles whose bearing surfaces must be hard, in order to resist frictional wear, of some form of machine steel, and give the surfaces sufficient hardness by case hardening, it is generally considered necessary to make cutting, forming and similar tools of tool steel.

It is practical, however, to make cutting tools for certain classes of work of machine steel, and harden the cutting edges sufficiently to produce very satisfactory results.

Steel is, as previously explained, a combination of iron and carbon. The grade of iron used in making tool steel is, however, vastly superior and much more expensive than that used in the manufacture of the ordinary machine steel. Being much purer, it is much stronger when carbonized and hardened, and consequently can do many times the amount of work of tools made of the lower grades of steel, even when these are charged with the *same* percentage of carbon. It is also less liable to crack when hardened, as the impurities contained in the lower grades make it, when combined with carbon, very brittle when hardened.

But notwithstanding the facts just presented, it is

possible to make tools for cutting paper, wood, lead, brass and soft steel of a low grade of steel, and harden it by a process that gives results much more satisfactory than would be thought possible by one who had never tried it. This method recommends itself on account of the comparatively low cost of the steel, and it can be worked to shape more cheaply than if tool steel were used. But it is usual, when the experiment is tried, to use any piece of low grade steel laying around the shop that will machine to shape in a satisfactory manner, not realizing that it is necessary, in order to get satisfactory results, to use steel adapted to the purpose. As phosphorus, when present in steel, and especially when in combination with carbon, causes it to be extremely brittle when hardened, a grade should be selected that has the least possible percentage of this harmful impurity.

If it is not necessary to have the hardened surface very deep, a steel having a low percentage of carbon may be used. If, however, the tool is to be subjected to great strains, it is advisable to use a steel containing sufficient carbon to cause the tool to harden enough to furnish the necessary stiffness or internal hardness. The extra amount of hardness necessary to insure the cutting portions standing up when in use, must be furnished by the process of hardening.

The writer has seen reamers, counterbores, punch press blanking, forming and drawing dies, and many other forms of tools made of low grade steel, which, the parties using them claimed, gave the best of results.

As before stated, when making tools which are not to be subjected to a very great amount of strain, or which will not be called upon to resist a great amount

of pressure, a steel low in carbon may be used. Any desired amount of surface hardness may be given the piece. If, however, the tool will be subjected to torsional strain, as in the case of a long, slender reamer, or if it may have to resist a crushing strain, as in the case of a punch press forming die, it is necessary to use stock containing sufficient carbon to furnish the desired result when hardened. If the tool is not to be subjected to very great strain, almost any low grade stock that is practically free from impurities will do.

If a long, slender reamer, or similar tool, is to be made, excellent results are claimed by using a low grade steel of 40-point (.40%) carbon. In the case of a forming die, or similar tool, use a steel of 60 to 80-point carbon. If, however, it was to be subjected to great pressure or very severe usage, the writer's experience leads him to advocate the use of tool steel specially adapted to this class of work.

As it is necessary, in order to get satisfactory results, to have the percentage of impurities as low as can be obtained, in order to have the hardened steel as strong as possible, do not allow it to come in contact with *any form of bone* when heating. The articles should be packed in a hardening box with a mixture of equal quantities (volume) of charred leather and granulated charcoal in the same manner as described under Pack Hardening. It will be necessary to subject the articles to heat for a longer period of time than if hardening tool steel. The length of time the articles are subjected to the action of the carbonizing element depends on how deep it is necessary to have the hardened portion. The test wires previously mentioned should be used to determine when the contents of the box are heated.

When in doubt about steel.

If you are reasonably sure the steel used was practically free from injurious impurities and is low in carbon, it may be dipped in a bath of water or brine. Should there be any doubt as to this, dip in raw linseed oil.

If the article being hardened is a cutting tool, or something requiring a fine, compact grain, better results will follow if it is left in the box after being subjected to the action of carbon, the box removed from the fire, and the whole allowed to cool. When cold, the article may be reheated to a low red, and hardened.

While the writer has used a low grade steel in making various forms of tools, and had excellent results when they were put to the use for which they were intended, he cannot recommend its use, unless the parties doing the work select stock suited to the purpose and exercise due care when hardening.

While this subject might properly be classed under the heading of Case Hardening, it has not seemed wise to the writer to do so, because case hardening, according to the interpretation usually given it by mechanics, is simply a process of transforming the surface of the article into a condition that allows it to become hard if plunged red-hot into water. Hardness is apparently the only object sought, but such is not the case when the subject is considered in its proper light.

When applying this principle to tools, it is necessary to consider the requirements of the tools. Knowing this, it is necessary to proceed in a manner that will give the desired results.

If it is considered advisable to make certain tools of a low grade steel, treating it as described, it is necessary to select steel adapted to the tool to be made.

It is never advisable to use Bessemer steel bought in the open market, because it does not run uniform. Always use open hearth steel, procuring it, if possible, of a quality that will give satisfactory results. Steel, with a very small percentage of phosphorus and other impurities, may be obtained from any reliable maker, if the purpose for which it is to be used is stated when ordering.

Special Steels.

To one interested in working steel, the history of the development of this industry furnishes a remarkably interesting study.

Steel may be grouped under four general heads, the name given each class being selected on account of the method pursued in its manufacture.

Probably the oldest of all known steels is the cemented or converted steel. This steel is made by taking iron in the form of wrought iron bars, packing them in a fire-brick receptacle, surrounding each bar with charcoal. This is hermetically sealed, and heat is then applied until the whole is brought to a degree of heat that insures the penetration of a sufficient quantity of carbon. Experience proves that carbon will penetrate iron at about the rate of one-eighth of an inch in twenty-four hours; and as bars of about three-quarter inch thickness are generally used, it requires three days for the carbon to penetrate to the

center of the bar (⅜-inch). The furnace is then allowed to cool, and the iron bars, which are converted to steel, are removed. They are found to be covered with blisters, hence the name, Blister Steel.

When examined, the bars are found to be highly crystalline, brittle steel. When this form of steel is heated and rolled directly into commercial bars, it is known as German Steel.

If blister steel is worked by binding a number of bars together, heating to a high heat, and welded under a hammer, it is known as Shear Steel, or Single-Shear.

If single-shear steel is treated as above, the finished product is known commercially as Double-Shear Steel.

Until within a comparatively few years these three classes of converted steel were practically the only kinds known in commerce.

Crucible Cast Steel.

As this is the standard steel used for fine tools, a brief study of the methods used in its manufacture may be of interest to the reader. Benjamin Huntsman, a clockmaker, is supposed to have been the inventor of this process. It occurred to him that he might produce a more uniform and satisfactory article than was to be had at that time for use in manufacturing springs to run his clocks. The method he had in mind consisted in charging into a crucible broken blister steel, which was melted to give it a homogeneous character.

While Huntsman thus founded the crucible steel industry, which has been of incalculable value to the mechanic arts, he met with many difficulties. These have been overcome by later inventions, notably those

of Heath and Mushet, until to-day it is possible, with skill and care, to produce a quality of steel which, for strength and general utility, has never been equaled, despite the claims of some blacksmiths that the steel of to-day is not as good as that produced 25 to 50 years ago.

Competition has rendered it necessary to run cutting tools, or stock, as the case may be, much faster than was formerly the case, which made it necessary to make steel containing a higher percentage of carbon than was formerly the case. As stated in a previous chapter, when high carbon steels are used, it is necessary to exercise great care in heating for the various processes of forging, annealing and hardening, As high carbon steels are more easily burned than those containing a lower percentage, it is necessary to put them in the hands of skilled workmen, for, unless the steel is to be worked by men understanding its nature, it proves to be a very unsatisfactory investment, and is often condemned because it will not stand as much abuse as a steel of lower carbon; but if properly treated, will do many times the amount of work.

Alloy Steels.

In order to accomplish certain results, steel is made containing other metals. To distinguish them from steels, which depend on the quantity of carbon present for their hardening properties, they may properly be termed "alloy" steels, the amount of the hardening property present determining the quality of the steel. As these steels can generally be run at a higher periphery speed and cut harder metals than carbon steels, they are very valuable at times, and in some

shops are used altogether. As a rule, they are more easily injured by fire than carbon steel, and, consequently, extreme care must be exercised when working them.

When high carbon steel is alloyed with other hardening properties, a steel is produced which will be found more efficient for machining chilled iron than the regular high carbon steels. However, as the nature of steel of this character depends entirely on the amount and kind of the alloy used and the amount of carbon present, no fixed rule can be given for the treatment. It is always best to follow as closely as possible directions received with the steel.

The writer has seen milling machine cutters, punch press blanking dies, and other tools, which were to cut very hard, "spotty" stock, give excellent results, when made from a reliable alloy steel, where carbon steels would not stand up.

If the amount of certain hardening elements be increased to a given point, the steel hardens when heated red-hot, and is exposed to the air. It is styled "Air Hardening Steel," more generally known, however, as Self-Hardening Steel.

Self-hardening Steel.

It was not originally the intention of the writer to mention self-hardening steel, because there are so many different makes of the article, each differing from the other to an extent that the method employed to get satisfactory results, when using one make, would prove entirely unsatisfactory when applied to another.

Self-hardening steel has a field of its own, and is very useful when made into tools for certain work. It

is used very extensively in cutting hard metals, and can be run at a high periphery speed, because the heat generated does not soften the tool, as is the case when carbon steels are used.

No *general* instructions can be given for working the steel, because the composition of the different makes varies so much that the treatment necessary, in order that one brand may work satisfactorily, would unfit another for doing the maximum amount of work possible for it to do.

A very common error in shops where a make of this steel is used, and another brand is to be tried, consists in attempting to treat the new brand in the same manner they have been treating the other, regardless of instructions furnished.

As previously stated, the treatment suited to one brand would render another unfit for use, and as the reputation of a brand depends on the results attained, the makers are very careful when selling steel to state plainly the treatment it should receive. The buyer should see that the directions are followed implicitly.

When purchasing self-hardening steel, it is advisable to investigate the merits of the different makes. In practice, certain brands prove best for cutting cast iron, while another brand, which will not do as much work when cutting cast iron, proves to be more desirable when working steel. Other brands, which give satisfaction when made into lathe and planer tools, prove useless when made into tools having projecting cutting teeth, as milling machine cutters, etc.

As previously stated, the different makes of self-hardening steel require different methods of treatment. One gives best results when worked (forged) at a full

red heat, while another requires a much higher heat. As the steel is less plastic when red-hot than most carbon steels, it is necessary to use *greater* care in regard to the manner in which it is hammered. A *heavy* hammer should be used, if a large section is to be forged, as it is necessary to have it act uniformly on the entire mass, or the surface portion will be drawn away from the interior, and, as a consequence, a rupture will be produced. Small pieces should be forged with lighter blows, or the steel will be crushed.

Do not attempt to forge when the temperature is lowered to a point where the steel loses its malleability, or it will be injured.

It is very necessary that a *uniform* heat be maintained throughout the piece. Do not think, when working a small section, that it is safe to forge when it has cooled to a *low* red, because some heavier portion has not cooled below a full red.

Do not allow the steel to cool off from the forging heat. After forging, place the piece in the fire again, and allow it to come to a uniform bright red. Do not allow it to "soak" in the fire, but it should be heated at this time without the aid of the blast. When it has reached a *uniform* red heat, remove from the fire, and allow it to cool in a dry place, not exposed to the action of any draft.

While most self-hardening steels will become hard enough when cooled in the air, it is sometimes necessary to have the tool extra hard. In such cases, it may be cooled in a forced blast. Some steels give better results if cooled in oil, others require cooling in hot oil, while others may be cooled in hot or cold water. Generally speaking, however, it is not advisable to bring

most brands of this steel in contact with water when red-hot.

While it is generally admitted that self-hardening steels are principally valuable for lathe, planer, and similar tools, when cutting hard metals or running at high speeds, there are makes which give excellent satisfaction when annealed and made into such tools as milling machine and similar cutters.

When it is necessary to have the stock in an annealed condition, it is advisable to procure it in this state, as the manufacturer, understanding the composition and nature of the steel, is in a position to anneal it in a more satisfactory manner than the novice. However, if it is considered advisable to anneal it in the factory where it is to be worked, it may be accomplished. Different makes of steel require treatments differing from each other, the treatment depending on the element used to give it its hardening qualities. Some brands may be annealed sufficiently to work in the various machines used in working steel to shape by heating to a bright red and burying in green pine sawdust, allowing it to remain in the sawdust until cool.

Most brands may be annealed by keeping the steel in an annealing furnace at a bright red heat for from twenty-four to forty hours, then covering with hot sand or ashes in the furnace, and allowing to cool. It should be about the same length of time cooling as it was exposed to the heat. It is necessary many times to machine it with tools made of the same quality of steel, on account of the natural hardness and density of the stock. It is claimed that tools made of certain brands of self-hardening steel give better results when cutting chilled iron than tools made of high carbon alloy steels.

The writer cannot substantiate this claim, as he has never been able to get as good results as when using an extra high carbon alloy steel, *properly* treated.

However, it is safe to say that used for machining (roughing) work in the lathe, planer, and similar machines, can be made to do many times the amount of work in a given time than would be the case were ordinary carbon steel tools used.

Much better results may be attained, however, than is usually the case, if makers' instructions are implicitly followed.

On account of the rapidly growing popularity of certain makes of this class of steel, many swindles have been perpetrated by unscrupulous parties, claiming to be representatives of a reliable house. A tool made, as they claim, from the steel they were selling is submitted for trial. It proves to be all that could be asked for, and a quantity of steel is ordered sent C. O. D. When this is received and paid for, it is found to be of no use. Parties purchasing steel of any but known and reliable steel concerns do so at a great risk, as a number of manufacturers have found to their sorrow.

Steel for Various Tools.

There is no one topic connected with this work that caused the writer so much anxiety as the one under consideration, because a temper of steel that gives entire satisfaction when used in one shop, would not answer when made into tools intended for the same, or

similar purposes, in a shop situated on the opposite side of the street. This is simply because in one case the operator who forged or hardened the tools understood handling the steel, and in the other case a man totally incompetent was entrusted to do the work.

Then again, steels of certain makes are more free from harmful impurities than others. A steel containing a low percentage of these impurities can safely have a higher percentage of carbon. Certain steels which are low in their percentage of phosphorus can have a greater amount of carbon than other steels which contain more of this harmful impurity.

A tool made of 1.4 per cent. carbon steel low in phosphorus will not cause as much trouble as if made of a 1.25 per cent. carbon steel containing a greater amount of phosphorus, but its capacity for cutting hard metals, and holding its edge when running at high speeds, is much greater.

Knowing the tendency in many shops to use a high carbon steel, and realizing the advantages of so doing, the writer would advocate the use of such steels, were it not for the fact in many cases the results have been anything but satisfactory, because men totally unfit for such work were employed to forge and harden the tools made from them.

But it has seemed wise to give the tempers of tool steel suited for certain purposes, the reader bearing in mind that in many cases it is safe and advisable to use a higher carbon, provided due care is exercised when working it during the various operations of forging, annealing and hardening. As previously stated, steel of a certain make and temper giving excellent results in one shop does not always give satisfactory results in

some other shop on the same class of work. Knowing from experience that the variable factor is the man working the steel, rather than the steel itself, the writer has deemed it wise to quote the experience of various steel makers, rather than results of his own personal experience.

Degree of Hardness	Percentage of Carbon	Should be used for
Very hard	1.5	Turning and planing tools for hard metals, small drills, gravers.
Hard	1.25	Tools for ordinary turning and planing, rock drills, mill picks, scrapers, etc.
Medium hard	1.	Taps, screw thread dies, broaches, and various tools for blacksmiths' use.
Tenaciously hard	.85	Cold sets, hand chisels, reamers, dies, drills.
Tough	.75	Battering tools, cold-sets, shear blades, drifts, hammers, etc.
Soft	.65	Battering tools, tools of dull edge, weld steel for steeling finer tools, etc.

While the foregoing table gives the tempers of steel that can safely be used for the purposes specified, it is many times advisable to use steel of a higher percentage of carbon.

Then again, it is sometimes best to use a low carbon steel of good quality, in order to get the maximum amount of toughness in the interior portions, packing the finished tool in a box containing charred leather, as

explained under Pack Hardening, and running for a sufficient length of time to get an extremely hard surface when hardened. By adopting this method, it is possible to get a cutting surface that will stand up when running at a high rate of speed, and yet be strong enough to resist extremely rough usage.

When it is desirable to get the steel *extremely* hard and very deep, in order to allow for grinding, and yet have the tool sufficiently tough to stand up, use a ***high*** carbon steel, pack in a box as described, running in the fire at an extremely low heat; quench in a bath of raw linseed oil.

In order to provide a guide for use in selecting steel suitable for various purposes, the following list is given. It is the result of the writer's experience, and information picked up here and there. A very noticeable fact, however, must be taken into consideration, namely: mechanics in the same class do not advocate the use of steel of like tempers, even when making tools of the same kind, to do the same class of work under the same, or similar circumstances, so no rule can be given arbitrarily.

The reader should, however, bear in mind that steels, which contain impurities to any considerable degree, cannot safely be used with the percentage of carbon mentioned. But as most of the leading steels on the market have received their standing because they are practically free from these impurities, it is safe when using them to use the percentages of carbon mentioned.

There are several makes of crucible tool steel on the market, which are exceptionally low in their percentage of impurities, and when using these, it is

safe to use a higher carbon than the one mentioned, provided due care is used when heating for the various operations of forging, annealing and hardening.

In the following pages the term crucible steel is intended to denote crucible tool cast steel.

The term cast steel is often misunderstood by mechanics, and many are of the opinion that any cast steel is tool steel. Such, however, is not the case, for the products of the Bessemer and open hearth processes are cast steel in the same sense that crucible steel is, yet they are not understood as tool steels, although products of both processes which were highly carbonized have been sold to parties as tool steel.

Arbors for saws.

Saw arbors, and similar articles, when made from crucible steel are made from a stock containing .60 to .70 per cent. carbon. When made from open hearth steel the percentage of carbon is about the same, although some manufacturers claim good results when a lower percentage is used.

Arbors for milling machines.

Milling machine arbors when made from crucible steel give good satisfaction if a steel of .70 to .80 per cent. carbon is used. Unless they are to be hardened, better results are obtained if the steel is worked to shape without annealing, as it is much less liable to spring when subjected to strain in use. In shops where great numbers of these arbors are used crucible steel is considered very costly. In such cases open hearth steel containing .40 to .60 per cent. carbon is often used. Many times a stock containing a higher percentage is used.

Augers.

Augers for wood-work are made from crucible steel of .70 to .80 per cent. carbon.

Axes

are made from crucible steel containing 1.00 to 1.20 per cent. carbon.

Barrels for Guns

are made from crucible steel containing .60 to .70 per cent. carbon, while some manufacturers use an open hearth steel containing .50 per cent. carbon, and others claim to use the same steel with .60 or even .70 per cent.

Centers for Lathes

are made of crucible steel containing .90 to 1.10 per cent. carbon.

Chisels for Working Wood

are made from crucible steel containing 1.15 to 1.25 per cent. carbon.

Chisels for Cutting Steel,

where the work is light, give good satisfaction when made from crucible steel containing 1.25 per cent. carbon.

Cold Chisels,

for chipping iron and steel, work well if made from crucible steel containing .90 to 1.10 per cent. carbon. Trouble with cold chisels is more often the result of poor workmanship than an unsatisfactory steel.

Chisels for Hot Work

may be made of crucible steel of .60 to .70 per cent. carbon.

Chisels for Cold Work,

for blacksmiths' use, are made of crucible steel containing .70 to .80 per cent. carbon.

Chisels for Cutting Stone

are made from .85 per cent. carbon crucible steel.

Cutters for Milling Machine Work

are probably made from a greater range of tempers than almost any other tool used in machine shop work, some manufacturers never using a steel containing over 1.00 per cent. of carbon, on account of the liability of cracking. Cracking is, however, a result of careless working, and as much more work can be done in a given time with a cutter made from a high carbon steel, it is, generally speaking, advisable to use such steels. Cutters, 2 inches and smaller, may safely be made from crucible steel containing 1.25 to 1.40 per cent. carbon. Cutters, 2 to 3 inches, 1.15 to 1.25. Larger than 3 inches, or if of irregular contour, 1.10 to 1.20 per cent. carbon. There are several alloy steels on the market which give excellent results when made into cutters of this character, provided extreme care is taken in heating.

Cutters for Pipe Cutting

may be made from crucible steel containing 1.20 to 1.25 per cent. carbon.

Cutters for Glass

are made from crucible steel containing 1.25 to 1.40 per cent. carbon.

Dies (Threading) for Bolts

and similar work, made from stock having rough, uneven surfaces, may be made from crucible steel containing .70 to .80 per cent. carbon. However, when the dies are hardened by the process described under Pack Hardening, steel containing 1.00 to 1.10 per cent. works nicely, stands well, and holds a good edge.

Dies for Screw Cutting,

to be used by hand or in screw machine, may be made from crucible steel containing 1.00 to 1.25 per cent. carbon.

Dies for Blanking or Punch Press

work are made from crucible steel containing .90 to 1.10 per cent. carbon. When the articles to be punched are small, and the stock to be worked is hard, steel containing 1.00 to 1.25 stands better than the lower carbon steel for small dies. Some manufacturers use a steel containing 1.25 to 1.40 per cent. carbon, provided it is low in percentage of impurities. When the work is not of a shape that requires great strength on the part of the die, open hearth steel containing .40 to .80 per cent. carbon is used. The die in this case should be hardened according to directions given for hardening tools made from machine steel.

Dies Used for Swaging

metals are made from crucible steel, the percentage of carbon varying according to the character of the work to be done. When the die is not to be subjected to very severe usage, a steel containing .90 to 1.10 per cent. of carbon may be used. Where a deeply hardened portion is desirable, a steel containing 1.20 to 1.25 per cent. works nicely.

Drawing Dies

are made of crucible steel containing 1.20 to 1.25 per cent. carbon.

Dies for Drop Forging.

As the product of different steel manufacturers varies so much, and the requirements are so varied for work of different kinds, it is advisable to submit the article to be made to some reliable steel manufacturer, letting him furnish a steel especially adapted to the work to be done. Ordinarily a crucible steel is used containing .40 to .80 per cent. carbon. However, many manufacturers consider it best to use a good quality of open hearth steel containing the proper percentage of carbon. Small dies, or those having slender portions requiring great strength, are made of the higher carbon.

Drills—(Rock Drills),

for quarry work, are made of crucible steel containing 1.10 to 1.25 per cent. carbon.

Drills—(Twist).

Small drills are made of crucible steel of 1.25 to 1.50 per cent. carbon, while larger drills require a steel of 1.00 to 1.25.

Files

are made of crucible steel of 1.20 to 1.40 per cent. carbon. Files of inferior quality are made of open hearth steel.

Hammers for Blacksmiths

use are made from crucible steel of .65 to .75 per cent. carbon.

Hammers for Machinists'

use are made from crucible steel of .85 to 1.15 per cent. carbon. For the ordinary sizes steel containing 1.00 per cent. works nicely.

Hardies for Blacksmiths

are made of crucible steel of .65 to .75 per cent. carbon.

Hobs for Dies

are made of crucible steel of .90 to 1.00 per cent. carbon, when they are to be used for cutting a full thread in a die. If they are to be used for sizing only, a steel containing 1.20 to 1.25 may be used, as it will hold its size and form longer than if made of steel containing less carbon.

Jaws for Bench Vises

are made from crucible steel of .80 to .90 per cent. carbon. Open hearth steel is, however, extensively used for this purpose.

Jaws for Chucks

are strongest if made of crucible steel containing .85 to 1.00 per cent. carbon, although many times they are made from a good quality open hearth steel.

Jaws for Cutting Pliers

are made from crucible steel containing 1.10 to 1.25 per cent. carbon. When they are to be used for cutting piano or other hard wire, they are made from steel containing 1.40 to 1.50 per cent. carbon.

Jaws for Gripping

work in various fixtures are made from crucible steel of .80 to .90 per cent. carbon.

Jaws for Pipe Machines

are made from crucible steel containing 1.00 to 1.20 per cent. carbon.

Jaws for Screw Threading Dies,

having inserted jaws or blades, are made of crucible steel of 1.00 to 1.20 per cent. carbon.

Jaws for Wire Pullers

are made from 1.00 to 1.20 per cent. carbon crucible steel.

Knife Blades.

When crucible steel is used, a stock containing .9 to 1.00 per cent. carbon is selected.

Knife Blades,

to be used for whittling and general wood-working, are made from 1.10 to 1.25 per cent. carbon crucible steel.

Knives—Draw Knives

are made from crucible steel of 1.20 to 1.25 per cent. carbon. Many times, however, they are made of open hearth steel.

Lathe Tools

for ordinary work are made of crucible steel containing 1.25 per cent. carbon. For turning hard metals or running at high rate of speed, use steel containing 1.40 to 1.60 per cent. carbon.

Lathe Tools.

For turning chilled iron, a high carbon alloy steel works better than a straight carbon steel.

When it is desirable to run at very high speeds, use a self-hardening steel.

Machinery Crucible Steel

contains .55 to .65 per cent. carbon.

Mandrels.

Custom differs in various shops. Some mechanics consider it best practice to make mandrels up to and including 1 inch of crucible steel, and for sizes above 1 inch advocate the use of machine steel, case hardened. Others claim best results from crucible tool steel for all sizes. Mandrels, however, do not require a steel containing as high a percentage of carbon as cutting tools. Small mandrels give good satisfaction when made from steel of from 1.00 to 1.10 carbon, larger sizes made of steel containing .80 to 1.00 per cent.

When mandrels are hardened by the process known as Pack Hardening, a steel containing .75 to .90 per cent. will give excellent results.

Mowers.

Lawn mower knives, .90 to 1.00 per cent. crucible steel, although in many instances they are made from open hearth steel.

Planer Tools for Stone,

.75 to .90 per cent. carbon crucible steel.

Planer Tools for Wood-working

machinery are made of crucible steel containing from 1.10 to 1.25 per cent. carbon.

Planer Tools.

If the tools are large and the metal to be machined is comparatively soft, crucible steel containing 1.25 works nicely. If, however, high speeds are desired or the metal to be cut is hard, a steel containing 1.40 to 1.50 per cent. carbon gives better results, provided care is exercised in heating for forging and hardening. If the stock to be cut is extra hard or it is desirable to run at speeds higher than is practical when using tools made from carbon steels, it is advisable to get a reliable self-hardening steel.

Punches for Hot Trimming,

.85 to 1.00 per cent. carbon crucible steel. Some mechanics claim as good results if the punch is made of open hearth steel of .60 to .80 per cent. carbon, while others make both punch and die of open hearth steel. These tools may be hardened in the ordinary manner or they may be hardened according to directions for hardening tools made of machine steel.

Punches for Blanking Work

in punch press. The percentage of carbon desirable depends on the stock to be cut and the skill of the operators doing the hardening If crucible steel is used, a range of .90 to 1.25 per cent. carbon is allowable, depending on the character of the work. Many times, however, such punches, if of a shape and size that insures strength, are made of .40 to .80 per cent. carbon open hearth steel, and hardened as explained under Making Tools of Machine Steel.

Punches for Blacksmiths

should be .80 to .90 per cent. carbon crucible steel

Punches for Railroad Track Work,

about .85 per cent. carbon crucible cast steel is advisable.

Reamers.

Small reamers, which are to be used continuously, should be made from crucible steel of 1.25 to 1.50 per cent. carbon. When they are to resist great strain, steel of 1.00 to 1.25 per cent. may be used. Excellent results will follow if steel containing .90 to 1.10 per cent. carbon is used, and the reamer hardened by the method described under Pack Hardening. This is especially true if the reamer is long or slender, or of a shape that betokens trouble when it is hardened.

Saws (Circular) for Wood,

about .80 to .90 per cent. crucible steel.

Saws for Cutting Steel

are made from 1.25 to 1.50 per cent. crucible steel.

Scrapers for Scraping Surfaces,

1.50 carbon crucible steel. Although many scraper hands claim best results from using a high carbon alloy steel.

Screw-Drivers,

small, .90 to 1.00 per cent. crucible steel; large, .65 to .80 per cent.

Stamps for Stamping Steel,

1.25 to 1.50 per cent. carbon crucible steel.

Shafts for High Speed Machinery

are many times made from crucible steel, containing .65 per cent. carbon.

Spindle Steel,

same as shafts.

Springs for Ordinary Purposes

are made from 1.00 to 1.10 per cent. carbon crucible steel. For many purposes, an open hearth steel is used with satisfactory results.

Springs for Locomotives

are made by some manufacturers of crucible steel containing .90 to 1.10 per cent. carbon, and by others of a steel containing .80 to .90 per cent., while in many cases very satisfactory results follow if open hearth steel, made especially for the purpose, is used.

Springs for Carriages

are made from crucible steel containing .80 to .90 per cent. carbon, but many more springs of this character are made from open hearth and Bessemer stock than from crucible, because it answers the purpose and is much cheaper.

Taps

are made of crucible steel containing 1.10 to 1.25 per cent. carbon in many shops, while others claim better results from steel containing 1.25 to 1.40 per cent.

Taps for Tapping Nuts,

generally called machine taps, give best results if made from steel containing 1.00 to 1.10 per cent. carbon.

Causes of Trouble.

While most of the causes of trouble when steel is hardened have been considered under the various topics presented, it has seemed wise to group together the more common causes, in order that they may be referred to more readily by the reader.

Uneven Heats.

Probably the most common cause of trouble is uneven heating of the piece in forging, annealing or hardening. As a consequence, violent strains are set up which cause the piece to crack or, in the case of heavy pieces, to burst. The different parts of the piece being unevenly heated, must, when cooled, contract unevenly; and when two portions of a piece adjoining each other attempt to contract unevenly—that is, one contracting more or faster than the other—and both being rigid to an extent that makes it impossible for them to yield one to the other, there must be a separation at the point where the uneven temperature occurs.

High Heats.

A very common cause of trouble consists in heating steel too hot for the purpose. High heats open the pores of the steel, making the grain coarse and causing the steel to be weak. When the piece is broken, it has

a honeycomb appearance—looks full of holes, so to speak. Now, as there is but a very thin layer of steel over these holes, when pressure is applied the surface over the holes caves in, and the steel is unfitted for doing the maximum amount of work.

Steel which has been overheated may be restored —unless the heat was high enough to burn or disintegrate the steel—by reheating carefully to the refining heat and quenching; but it can never do the amount of work possible, had it not been overheated. Yet, it will be much better than if left in the condition the high heat placed it.

Then again, high heats have a tendency to cause the steel to crack when hardened. This is especially true if the piece be cylindrical in shape. Cylindrically shaped pieces will not stand the amount of heat that may safely be given a piece of almost any other shape without cracking, although the effect on the grain and the ability of the steel to stand up and do the maximum amount of work possible would be the same in any case, regardless of the form of the piece or the method of applying the heat.

Too Rapid Heating.

While it is advisable to heat steel as rapidly as possible consistent with good results, it should not be heated *too* rapidly, as corners and edges will become overheated before the balance of the article has reached the proper heat; and even if they are allowed to cool down to the proper heat (apparently), the grain has been opened at these portions, and violent strains are set up. This is one of the places where experience seems to be the only guide and where the instructor

can only give suggestions, which should be heeded and worked out by each hardener.

Heating Too Slowly.

In attempting to avoid heating too rapidly, do not go to the opposite extreme and allow the steel to "soak" in the fire, or soft surfaces will result, and the steel is not as good as if heated properly.

Fire Cracks.

There are a number of causes for steel cracking in the fire. Among the more common are, first, the cold air from the blast, if the work is heated in a blacksmith's forge. Then again, it may be heated in a gas flame having an air blast. The air may be turned on too much, resulting in cold air jets striking the heated steel. If a charcoal fire is used, it is the custom of some hardeners to throw cold water on the fire. Now, if the steel is red-hot, the water has a tendency to cause it to crack in the same manner as if the air from the blast came in contact with it.

Large articles plunged in a crucible of red-hot lead, cyanide of potassium, or any substance where they are exposed to violent heats, are very liable to crack, especially if there are heavy and light portions adjoining each other. The unequal expansion tears the steel apart at the point where the unequally heated portions adjoin each other. This may be avoided by heating the articles nearly to a red in some form of fire where it would heat more slowly, then plunge in the lead to bring to the desired heat; or, the article may be immersed in the red-hot contents of the crucible, left for a moment and withdrawn, immersed again, leaving a

trifle longer, and so continue until it reaches the desired heat.

If a piece of steel is immersed in a crucible of red-hot lead or similar material for a certain distance so that part of the piece is out of the red-hot material, it should be moved up and down in the molten mass, or the part below the surface will expand more rapidly than the adjoining metal. If the article were immersed and withdrawn, repeating this operation until the desired result is obtained, the heat being applied gradually, the expansion is more uniform, and the heat is imparted to the adjoining stock so it can yield to an extent that does away with any tendency to crack.

Cold Baths.

Extremely cold baths are the cause of a great deal of trouble when pieces of irregular contour are hardened. It is nearly always advisable, when hardening articles made of high carbon steel, to warm the contents of the bath somewhat. Many hardeners claim that oil heated to a temperature of 100 degrees to 120 degrees will harden steel harder than if it were extremely cold. It will certainly cause it to be tougher.

Improper Forging.

This is the cause of a great amount of trouble when steel is hardened. While the writer claims best results from steel properly forged, he is aware that much better results are obtained from steel machined to shape than if the articles were heated or hammered in any but a proper manner.

Steel to be made into tools whose cutting edges are on or near the end should not be nicked with a chisel

and broken, as the portions at the end are rendered unfit for cutting purposes.

Do not straighten steel that is to be hardened without heating it red-hot.

Do not attempt to harden a tool of irregular shape unless it has been annealed after blocking out to somewhere near to shape.

Do not take it for granted that because you have held a piece of steel in the fire and stuck it into water, it is necessarily hard. Try it with a sharp file before brightening the surface preparatory to drawing the temper, as much valuable time may be saved if the piece should prove not to have hardened.

When you get a piece of steel that you are in doubt about, it is advisable to cut a small piece of it from the bar and harden it, noticing the amount of heat necessary to produce desired results. If this is not done, trouble may follow when the article is hardened. It is better to experiment with a small piece of steel than with a costly tool.

Do not use any but *chemically* pure lead in a crucible intended for heating tools, or you will not get as good results as you might otherwise have.

Do not think that because the surface of red-hot lead appears to be at about the proper heat, that the contents nearer the bottom of the crucible are necessarily of the same temperature; because, generally speaking, the deeper you place a piece of steel in the contents of the crucible the hotter it becomes. Being ignorant of this fact, workmen spoil many valuable articles, and then think the lead has an injurious effect on the steel, not knowing that it is the amount of heat given rather than the method used in applying it that

caused the trouble. Impure lead will injure the surface of the steel, but will not alter the appearance of the grain if the temperature is right.

Remember that steel heated for annealing should not be subjected to heat for a longer period of time than is necessary to produce a *uniform* heat of the desired temperature. Steel overannealed does not work as well in the various operations of machining, neither will it harden and temper as satisfactorily as though properly treated.

Remember that heating is a process of softening steel, and cooling is a hardening process. The slower the process of cooling is carried on the softer the steel will be; consequently, it is never advisable to place red-hot steel that needs softening in cold or damp lime or ashes.

Always use a clean fire. Dirty slack fires are a source of a great amount of trouble, as they cause the surface of the steel to be covered with a sulphurous oxide.

A fire of new coals should be used (when using a charcoal fire) for heating steel. Dead coals require more blast than is good for the steel.

Ten pieces of steel are cracked as a result of *uneven* heating to every one that is the result of a defect in the steel.

Do not think that because the surface of a hardened piece of steel is not scaled that it is not overheated. Every degree of heat given it above that necessary to produce the desired result unfits the steel for doing the maximum amount of work possible for it to do.

Always harden on an ascending heat. Never heat a *little* too hot and allow to cool down to the *proper* heat,

as the grain of steel remains in the condition the last heat leaves it. To refine, it is necessary to allow it to cool off, and then reheat to the proper hardening heat.

It often happens that the hardener is blamed for things he is entirely innocent of. A man in this position is liable to have enough spoiled work to account for that is the result of his own carelessness or ignorance without being obliged to shoulder the shortcomings of others. It may be that some careless blacksmith has forged a tool at heats which unfitted the steel for the purpose for which it was intended. He may have heated the steel too hot, and opened the grain, causing brittleness, or he may have had uneven heats when he was forging, thus setting up internal strains which would cause the steel to crack when hardened. Then again, the tool maker may have attempted to straighten the piece without heating it red-hot, in which case it is almost sure to spring when hardened. Or, in the case of a long reamer or tap, the flutes may have been milled with a dull cutter, which would, of course, get duller the longer it was used, with the result that by the time the last flute was milled the tool would have been stretched very materially. This is especially true on the side where the last cuts were taken, as the cutter would be duller than when the flutes on the opposite side were milled, and the uneven stretching of the stock would, of course, spring the reamer.

Another difficulty would also present itself. The dull cutter would glaze the surface of the tooth that came in contact with the dulled portion of the mill, and any surface of steel which is glazed, whether it be from the action of cutting tools or grinding wheels, will not

harden in a satisfactory manner. This difficulty is more pronounced in the case of a piece glazed from the action of grinding wheels. While a glazed surface might not be considered objectionable, if it was to be ground away after hardening, yet it is not always considered advisable to grind the cutting faces of reamer and milling machine cutter teeth. There is no good

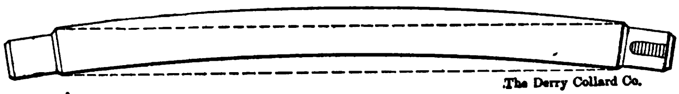


Figure 156. The spring of a mandrel.

excuse for using dull tools when machining steel. Not only does it lead to trouble when the pieces are hardened, but it is a means of wearing the tools out much faster than if they were kept sharp. Neither can as much nor as good work be done with dull tools.

It is often the case that a careless workman will mill the flutes in a long reamer, tap, or similar tool, without supporting the work properly. In this way the tool is sprung, first one way, then the other. This not only results in a crooked tool, but there is no knowing where it may go when hardened. Many times hardened pieces are sprung by heating when grinding. This is especially true with pieces that may have sprung when hardened. Take, for instance, a long mandrel which may have gone in the direction shown in Fig. 156. Now, if this mandrel were placed in a grinder and ground in a manner that caused it to become heated on the side that is already curved out, as shown in cut, it would spring still more.

Many times thin, flat pieces are sprung from the

expansion of one side when ground in a surface grinder. The side which comes in contact with the wheel becomes heated, while the opposite side, from contact with a mass of cold iron—the table—remains cool. The side which heats must expand, with the result that the piece is curved in the direction of the heated side.

When flat pieces which are hardened are ground with a glazed wheel or one too fine for the purpose, they are very liable to crack, commencing at the edge or end where the wheel leaves the work. Fig. 157 represents a rectangular gauge which cracked as a result

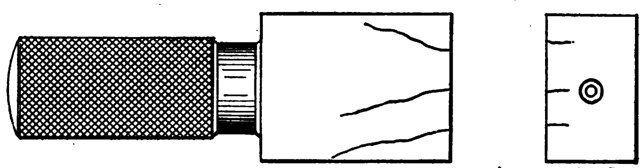


Figure 157. Cracked gauge.

of grinding. The fault was laid at the hardener's door, and he, poor fellow, was doing his best to harden the gauges in a satisfactory manner, so he said the steel was no good. An investigation showed the cracks to be from the end where the wheel left the gauge when grinding in the surface grinder. The vise which held the piece was turned one-quarter way around, and it was found that the cracks were from one *side*, instead of the end of the piece. An examination of the wheel revealed the fact that it was too fine for the purpose, and that it was badly glazed. A coarse wheel, free from

glaze, was substituted and the gauges were found to be sound after grinding.

Not only may hardened steel be sprung and cracked from heat generated when grinding, but it may also be cracked if water is run on it, unless due care is observed. If the operation is hurried to the extent that it becomes heated, even when the water is running on it, the water cools the piece, which is instantly heated again and then cooled. This sudden expansion and contraction causes the steel to become cracked in innumerable places, these cracks running in all directions. This trouble may occur when grinding pieces of almost any shape. The cracks may occur on the surface of a cylindrical piece, on the flats of a square, or on the face of an article being ground. Fig. 158 represents a disc whose face was cracked, as represented, when ground, with a stream of water running on the work. The fault did not lay in using water, but in forcing the grinding faster than the wheel could properly cut the metal.

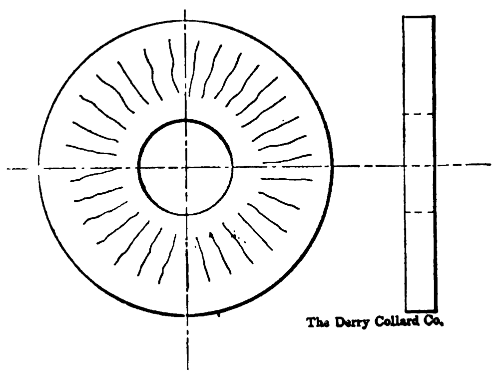


Fig. 158. Disc cracked from being ground too rapidly.

These few facts are pointed out, because it often happens that when these troubles arise, the party doing the hardening is blamed, and unless he is sufficiently

versed in the action of emery wheels on surfaces of steel, he naturally thinks the fault is either in the steel or in his method of treating it.

Very often milling machine cutter teeth are softened when ground, the hardener being blamed as a consequence. It is not good practice to use a very fine wheel when grinding tools of this description, neither should too hard a wheel be used. Ordinarly an emery wheel made of 60 to 90 emery will be found about right, and be sure the face of the wheel is not glazed. Should it become glazed, use a piece of emery wheel somewhat coarser than the one in use to remove the glaze. This also makes the face of the wheel open, and lessens the liability of heating.

Many times the writer has seen workmen using a tool ground in a manner that made it impossible for it to *cut*. It was forced into the stock, and broke it off. The tool could not stand this treatment, and gave right out, the workman in the meantime saying things about the hardener. When the tool was properly ground, it worked all right.

Some mechanics do not seem to realize that there is a proper speed to run stock or cutting tools, in order to get desired results. As a consequence, they either run them much too fast, with the result the tools can not stand up, or they are afraid they will exceed the proper speed, and, as a consequence, do not produce anywhere near the amount of work they might.

When cutting a key way or spline in a tool that is to be hardened, the tool maker should avoid sharp corners, as they are an invitation for a crack when the steel is rapidly cooled in the bath. While an article having sharp corners is not as liable to crack when

hardened by the process termed Pack Hardening as when treated in the ordinary manner, it is not advisable to in any way weaken a tool, or give it an invitation to crack. Consequently, avoid sharp corners as far as possible, or cuts or deep scratches that tend to weaken the article.

A milling machine cutter, made with light, weak teeth, can not be made to stand up when in use; the teeth being slender and weak, break like pipe-stems. Cutters with teeth of this description require greater care when hardening, to avoid overheating. Being slender, they spring and break. Do not blame the hardener if they fail to give satisfaction when in use.

Another source of trouble is fine teeth in milling cutters, reamers, and similar tools. The teeth, being fine, fill with chips, and in the case of milling machine cutters, the oil not being able to get to the teeth, can not conduct away the heat generated, which has the effect of drawing the temper to a degree that makes it impracticable to use them.

A short time ago the writer's attention was called to a side tool for use in an engine lathe. The tool was made from a well-known brand of steel, which is generally considered one of the best steels on the market. It was claimed that the tool could not be made to keep an edge on a mild grade of machine steel running at a periphery speed of 30 feet per minute, taking a fair cut.

An examination of the tool revealed the fact that it was ground in such a manner that the cutting edge had no backing. It might possibly have stood up if the material being machined had been wood instead of steel. Because the tool would not stand, the hardener was considered as being to blame. When

properly ground, it stood up all right *without* re-hardening.

Milling machine cutter teeth are many times ground with too great an angle, and the cutting edge, not having backing, gives way. Or it may not be given as much clearance as it should have. As a consequence, the heel of the tooth rubs, and the friction resulting trom this contact of the heel of the tooth with the material being machined produces heat, which softens the tooth. It is tried with a file, found to be soft, and the hardener is blamed.

Many times the liquid supplied to keep cutting tools cool, and to lubricate the cutting edges, can not reach the cutting edges of the tool. As a consequence, it becomes heated and the temper drawn. This is especially liable to happen to tools used on automatic screw machine work, where heavy cuts are being taken.

Twist drills, used in drilling very deep holes in steel, are very liable to receive insufficient lubrication, unless supplied with oil tubes, because the oil which is fed down the flute is forced back by the action of the chips and the angle of the flutes.

Taps are allowed to become clogged with chips, and break; the hardener is blamed, because the tap, it is claimed, is too hard. Broaches break from the same cause, and the trouble is placed at the hardener's door. Reamers are allowed to become clogged, the cutting edge chips off, and it is said the steel is burnt.

Cases of this character might be enumerated by the thousands, but it is needless. The tool maker should bear in mind that a place must be provided for the chips made when a tool is cutting, or roughly machined surfaces or broken tools (possibly both) must follow.

Welding.

When it is considered necessary to join two pieces of iron, thus making them one, or when it is desirable to join the two ends of a bar, thereby making a ring, it is accomplished by the process called welding.

This is of inestimable value as applied to the mechanic arts. Not only may iron be welded to iron, but steel may be joined to steel by this process. Iron may also be joined to steel.

It is accomplished by heating the metal to a temperature that makes the surface of a pasty consistency, which for soft steel should be a dark white, for iron a scintillating white, while for tool steel it should be a bright yellow. The formation of a soft pasty layer on the surface of the steel is an absolute necessity, in order to effect a union of the pieces of metal. This operation is assisted by scattering fusible substances on the surfaces to be united, as these protect the work from oxidation. These substances are termed *fluxes.* Among those most commonly used are borax, clay, potash, soda, sand and sal ammoniac. Ordinary red clay, dried and powdered, is an excellent flux for use when welding steel, and is one of the cheapest known. Borax melted and powdered is called the best of known fluxes, but it is so expensive when used in large

quantities, that its use is confined to the finest tool steels and alloy steels where it is not possible to heat the metal as hot as a lower grade of steel.

A very good flux, whose cost is about one-half that of borax, is a mineral barite, or heavy spar. It does not fuse as readily as borax, however, but forms an excellent covering for the heated surface of the steel. It is necessary to furnish this coating for the surface of the steel, in order to prevent oxidation; for if any portion is oxidized, no matter how small the portion may be, it furnishes a starting point for a break or fracture when the piece is under heavy stress. Although steel may be welded, it is a job to be avoided when the welded piece requires hardening.

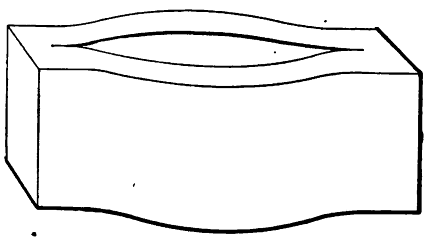
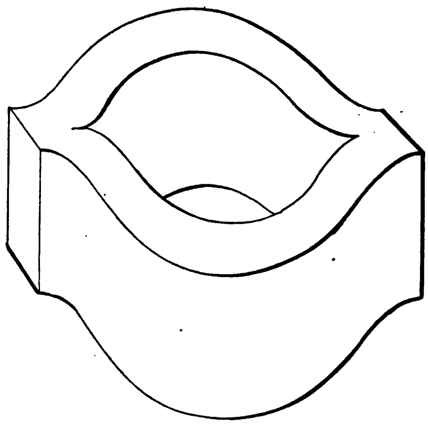


Figure 159. First operation on special swaging die.

Pieces are welded and afterwards hardened which remain intact, but it is not advisable unless the weld is to be made by a smith skilled in this particular branch of the business, and even then it is attended with varying results.

The writer was at one time connected with a manufacturing concern who built 50 machines for swaging wire. The operation of reducing the diameter of the wire was accomplished by dies known as swaging dies. These were actuated by hammers working inside of a large ring. This ring was made of tool steel, and in order to save expense, it was considered

advisable to take flat steel of the desired size to allow for finishing all over, bend in the form of a ring and weld the ends. A very skillful smith was given the job, but when finished and hardened, the rings broke apart at the weld. When broken to examine the grain, it was evident that the smith had used extreme care, yet a small portion of the welded surface was found to be oxidized; consequently, it could not unite at that place, and a rupture started from that point.



The Derry Collard Co.

Figure 160. The special swaging die finished.

The method of procedure was changed, stock sufficiently large was procured and split, as shown in Fig. 159. It was then opened until it resembled Fig. 160, and was afterward hammered to shape. Before shaping by hammering, however, the sharp corners were removed by means of a chisel. After machining to the desired size to allow for grinding, they were hardened as described under Hardening Large Rings, with the result that not one was lost.

While steel can be welded if great care is used, it is very apt to result disastrously if the steel is to be hardened. Not only has this been the writer's ex-

perience. but it seems to be the experience of most practical writers on the subject.

Other Things.

Substitute for Borax.

The following rule for preparing a substitute for borax for use in welding high carbon tool steel was given the writer several years ago by a blacksmith who was considered as an expert in welding steel. He claimed that steel could be welded by use of this flux at a lower temperature than is required with borax:

Copperas..............	2 ounces.
Common Salt..........	6 "
Saltpetre..............	1 ounce.
Black Oxide Manganese.	1 "
Prussiate of Potash.....	1 "

All pulverized and mixed with 3 lbs. good welding sand.

Charred Leather.

While it is possible to purchase charred leather of a desirable quality, so much depends on the condition of this article that it is always advisable to prepare it in the shop where it is used, if possible.

Use heavy leather, as scraps left when shoe soles are punched. Never use light leather, as there is little

goodness in it after charring. The very best article for the purpose can be procured from shoe shops.

To char the leather, fill one or more hardening boxes with small pieces, place the cover in position and seal with fire-clay. Place in the furnace, leaving it just long enough to char sufficiently, so it can be pounded fine. Do not expose it to the action of heat long enough to destroy the "*goodness*" of the leather.

A very satisfactory method is to fill boxes, 9x9x36 inches, with the leather scraps, sealing the covers as described, and placing them in the furnace at night after the work has been withdrawn. The remnant of fire and the heat of the furnace are sufficient to char the leather during the night. As previously stated, do not overchar. It should be exposed to the action of heat only long enough to break in pieces readily when pounded. If smaller boxes are used, it is not advisable to leave in the furnace over night. They must be watched, and taken out when the leather is charred sufficiently.

Charred Bone for Colors.

It is necessary, in order to obtain nice colors, that the work be polished and absolutely clean; unpolished surfaces will not color. Grease also prevents the obtaining of satisfactory work.

Pack the work in boxes as previously described, except that charred bone is used as packing material. When it has run the proper length of time, remove the box from the furnace, and dump into a tank of water having a jet coming up from the bottom. Better colors are obtained if a bath is used having an air pump con-

nected with the inlet pipe, as illustrated in Fig. 134. This shows an easy way of putting in an air pipe, connected with inlet water pipe. Soft water in the bath gives much better results than hard, although very satisfactory results may be obtained with hard water if the air pipe is connected as described. When hardening for colors by the method under consideration, it is essential that the box be held very close to the top of the water when dumping the work; the box should be inverted quickly, to prevent the air striking the work before it reaches the water. If the air comes in contact with the metal, the surface assumes a blue-black color. This is sometimes desirable, but not in connection with work packed especially for hardening for colors.

When the work is cold, it may be removed from the bath and boiled in clean water. Dry in sawdust, and oil the surface either with sperm oil or vaseline. This has the effect of making the colors more prominent, and it will also keep the steel from tarnishing or rusting.

To Char the Bone.

It is sometimes considered desirable to use bone rather than leather, and it is thought that the expended article would not give the necessary hardness. Yet it may be necessary that the articles be tough. This may be accomplished by taking raw bone, filling a small hardening box with it, placing the cover in position, and sealing with fire-clay. When the day's work of hardening is taken from the furnace, the box may be placed in it, the door shut, the fire extinguished, and the box left until morning. If the furnace is one

having light walls, that would lose their heat rapidly, it would be found necessary to apply the heat for a time. The bone will be found charred when the box is opened. Care should be observed that the charring is not *overdone*, however.

Charred bone may be used as packing material either alone or with an equal quantity (in volume) of granulated wood charcoal.

Preserving the Bone.

When the hardened articles are removed from the bath, the water may be drawn off, and the packing material taken out and dried. This may be done by placing it on top of the hardening furnace, if that be of sufficient size; if not, it may be spread out thinly and allowed to dry. This is the expended bone previously mentioned.

Expended bone may be used for packing certain classes of work in, or it may be mixed with an equal quantity of granulated raw bone and used the same as raw bone. Or it may be used for packing machine steel forgings or small articles of cast iron for annealing.

High Speed Steels.

During the past few years various makers have placed on the market steels that have revolutionized certain manufacturing methods. Cutting tools made from these steels will retain a cutting edge when extremely high speeds are employed; they are also useful when machining stock, which is too hard to be machined by ordinary tool steels.

This grade of steel when adopted by a certain concern allowed them to reduce the expense of machining stock to a degree that made it necessary for their competitor to use it also, in order to produce his work at a similar cost. As the steel was used it was found that the ordinary machine was not strong or stiff enough to do the work the tools made from it were capable of doing, and for this reason many concerns have found it necessary to purchase machinery made especially to accommodate these tools.

Extravagant claims are many times made by the manufacturers of these tools, claims which it seems were better not made; because the man who attempts to duplicate them and fails, not only loses faith in them but is skeptical regarding other steels when his attention is brought to them.

Failure to realize all that has been claimed for the steel may not always be the fault of the steel; it may come

from other causes. First, the operator not being familiar with the nature of the steel, may fail to treat it properly when making it into cutting tools. Then again the stock being machined with the tools may be entirely different in composition from that used when making the tests.

It is an unfortunate fact that most tests are made with nice, clean, easily machined, cast iron when that is the material used; or with soft machinery steel, free from hard spots. Now every mechanic knows that cast iron as it comes from the ordinary foundry to the machine shop, is a varying factor; it may machine easily and we may be able to get high speeds even when taking heavy cuts, and using coarse feeds; on the other hand, the composition may be such that the same tool would not stand up if we were to run it only half as fast as when machining the softer metal.

At one time while making experiments with one of the best known makes of high speed steels, the writer was able to run a piece of cast iron in the lathe at a speed of 100 feet per minute, the cut was 1-16 inch (removing 1/8 inch of stock) and the feed 20 to 1 inch. The tool stood up nicely and turned the entire length of the piece without dulling so that it was noticeable. When we attempted to turn another piece from the same pattern which was cast from a different mixture it was found impossible to retain a cutting edge on the tool if a speed of 45 feet per minute was exceeded, retaining, of course, the same depth of cut and relative feed.

Results even more noticeable than those mentioned above are experienced when cutting what is familiarly known as machinery steel, as unfortunately all grades of steel between wrought iron and tool steel are classed under the head of machinery steel.

Results are comparative.

These facts are not mentioned to in any way belittle the value of the steel under consideration, but to show the reader that he should not get discouraged when he fails to get results paralleling those claimed by the makers of the steel. The only fair method of judging of the value of the steel to the individual is to test in comparison with the best tool he can obtain, from tempering steel.

Because a tool will not stand up on cast iron running at 100 feet per minute, as claimed by the maker of the steel, is no proof the steel is no good. It might have stood all right at 90 feet, and perhaps a tool made from ordinary tempering steel might not have stood a speed of 30 feet; in which case the high speed steel was capable of doing more than three times the amount of work of the other.

Many times a difference in cutting speed of only a few feet per minute will cause a tool to either stand well, or go down.

There is no *general* set of instructions that can be given for working this steel, as a method that proved perfectly satisfactory on one would render another unfit for use. For instance, the writer at one time contributed an article to one of the mechanical journals on the subject of "High Speed Steel," recommending extremely high heats when hardening. Shortly after the appearance of the article a letter was received from a manufacturer of a brand of this steel, saying he had read the article with much interest and agreed with everything in it except the temperature necessary when hardening, as they had found their steel gave best results when it was hardened at a *low* cherry red heat.

A trial of a tool which he sent proved it to be equal or superior to some that were hardened at the high heat mentioned.

Follow maker's directions.

To get satisfactory results with any brand the party using the steel should follow instructions sent with the steel as closely as possible.

It is evident to the writer from results of his own experiments and the experience of others, that when this steel is thoroughly understood, results way beyond those we are at present getting will be obtained marvelous as *they* seem now.

While the writer has made extensive experiments with the steel under consideration, and has taken advantage of every opportunity to study its composition, this study has been confined to printed statements made by those who claim to possess this knowledge.

Knowing, however, that the successful man in any line of business is he who, by studious effort makes himself master of his subject,—what is more natural than that the student considering this subject should be anxious to know the composition of this steel.

The following is an abstract of a paper read by Mr. J. M. Gledhill before the "Iron and Steel Institute," October, 1904:

The high speed steels of the present day are combinations of iron and carbon with: (1). Tungsten, Molybdenum and Chromium.

We will consider the influence of each of the elements entering into the various compositions.

Influence of carbon

A number of tools were made with the carbon percentage varying from 0.4 per cent. to 2.2 per cent. and the method of hardening was to heat the steel to the highest possible temperature without destroying the cutting

edge, and then rapidly cooling in a strong air blast. By this simple method it was found that the greatest cutting efficiency is obtained where the carbon ranges from 0.4 per cent. to 0.9 per cent. and such steels are comparatively tough. Higher percentages are not desirable because greater difficulty is experienced in forging the steels and the tools are inferior. With increasing carbon contents, the steel is also very brittle, and has a tendency to break with unequal and intermittent cutting.

Influence of Chromium

Having found the best carbon content to range from 0.4 per cent. to 0.9 per cent., the next experiments were made to ascertain the influence of chromium varying from 1.0 per cent. to 6.0 per cent. Steels containing a low per centage are very tough and perform excellent work on the softer varieties of steel and cast iron, but when tried on harder materials the results obtained were not efficient. With an increased content of chromium the nature of the steel becomes much harder, and greater cutting efficiency is obtained on hard materials. It was observed that with an increase of chromium there must be a decrease in carbon to obtain the best results, for such percentage of chromium.

Mention may here be made of an interesting experiment to ascertain what effect would be produced in a rapid steel by substituting vanadium for chromium. The amount of vanadium present was 2.0 per cent. The steel readily forged and worked very tough and was hardened by heating to a white heat and cooling in an air blast. This tool when tried on medium steel stood well, but not better than the steel with the much cheaper element of chromium in it.

Other alloys.

Influence of Tungsten

This important element is contained in by far the greater number of the present high speed steels in use. A number of experiments were made with the tungsten content ranging from 9.0 per cent. to 27.0 per cent. From 9.0 per cent. to 16.0 per cent. the nature of the steel becomes very brittle, but at the same time the cutting efficiency is greatly increased and about 16.0 per cent. appeared to be the limit, as no better results were obtained by increasing the tungsten beyond this figure. Between 18.0 per cent. and 27.0 per cent. it was found that the nature of the steel altered somewhat and that instead of being brittle it became softer and tougher, and whilst such tools have the property of cutting very cleanly they do not stand up so well.

Influence of Polybdenum

The influence of this element is still under investigation and our experiments with it have produced excellent results, and is was found that where a large percentage of tungsten is necessary to make a good rapid steel, a considerable less percentage of molybdenum will suffice. A peculiarity of these molybdenum steels is that in order to obtain the greatest efficiency they do not require such a high temperature in hardening as do the tungsten steels, and if the temperature is increased above 1,800 degrees F. the tools are inferior and the life shortened.

Influence of Tungsten with Molybdenum

It was found that the presence of from 0.5 per cent. to 3.0 per cent. molybdenum in a high tungsten steel slightly increased the cutting efficiency, but the advantage

gained is altogether out of proportion to the cost of the added molybdenum.

Influence of Silicon

A number of rapid steels were made with silicon content varying from a trace up to 4.0 per cent. Silicon sensibly hardens such steels, and the cutting efficiency on hard materials is increased by additions up to 3.0 per cent. By increasing the silicon above 3.0 per cent., however, the cutting efficiency begins to decline. Various experiments were made with other metals as alloys, but the results obtained were not sufficiently good by comparison with the above to call for comment.

Analysis of one of the best qualities of rapid steels produced by Mr. Gledhill's firm (Armstrong Whitworth Co.), is as follows: "A. W." steel Carbon 0.55 per cent; Chromium, 3.5 per cent.; Tungsten, 13.5 per cent.

Tools made from high speed steels in order to give best results when heavy cuts and coarse feeds are employed, should be made of a form that insures strength and rigidity and must cut freely. Many times tools are made having very *little* clearance on the portion that penetrates the stock as shown at A Fig. 161; now if a coarse feed is employed it is apparent that such a tool will bear on the stock below the cutting edge, as a consequence the tool cannot cut as rapidly as the lathe carriage is traveling and it must turn in the tool post. If the operator is not attentive he will not observe the trouble, and in order to securely fasten the tool he will tighten the binding screw so tightly that he either breaks the tool post binding screw or he succeeds in binding the tool so it cannot turn, and the feed belt slips, or the pressure against the stock actu-

ally crowds off a portion of the cutting edge of the tool. It is necessary when taking heavy cuts with coarse feeds to give a tool sufficient clearance as shown at B. Fig. 161, so no part of the tool below the cutting portion will touch. Too much clearance, of course, weakens the tool and is to be avoided.

While slender side tools, diamond point, and similar tools, give excellent results when made from high speed

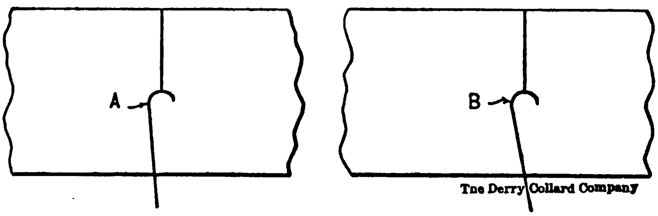


Figure 161. Side clearance of tools.

steel, the more noticeable results are obtained when heavy cuts are taken. To accomplish this it is necessary to use tools which are stubbed and strong and having as little *top rake* as is consistent with fairly easy cutting. For this reason tools having portions standing out from the shank (as a diamond point tool) are not generally satisfactory. A tool made as shown in Fig. 162, will be found to give best results when heavy cuts are taken.

Many tools are on the market which use separable cutters. These cutters may be of high speed steel which can be purchased in any of the common forms and sizes. The steel as it comes in the bar is glass hard unless it is ordered annealed. However, if *best* results are desired, it is advisable to harden it before using even when it is ***not*** necessary to forge it to shape.

To anneal or not to anneal.

If it is desirable to have the steel in the annealed condition, better results are obtained, generally speaking, if it is *purchased* in this condition, than if annealed in a shop that does not have the necessary facilities for maintaining a heat for a considerable length of time.

There is a difference of opinion among mechanics using this steel as to effect of annealing on the hardened

Figure 162. A good tool for heavy cuts.

tool, some claiming that tools made from steel that has been annealed will not stand as much as if made from stock that had not been annealed, while others claim best results from steel that has been annealed. The writer in his experiments has failed to notice any material difference, provided due care had been experienced in the various operations.

The writer saw not long ago some drills made from bars of a well-known brand of this steel which was not annealed. The steel was flatted, then twisted to shape while hot. After being hardened they were ground to size. They certainly stood up much better when tested than drills made from other brands whose grooves were milled from annealed bars. Whether the difference was due to the fact that one steel was annealed and the other not, or to the difference in the method of making, the writer is not ready to say. This much he does know; the

drills referred to were heated to a high heat and quenched in luke warm brine, while no one knew how the others were hardened. It would not be safe to dip some brands of this steel in brine, while others work nicely when tools of certain shapes are hardened in it.

When making certain tools, as taps, milling machine cutters, dies of various kinds and similar tools it is *necessary* to anneal this steel in order that it may be worked to shape, and unless it is *properly* annealed it is very trying, as well as extremely costly, to attempt to machine it to form.

The writer has made exhaustive experiments in the annealing of this steel and has found that some of the methods advocated, work in a manner that is anything but satisfactory. It is necessary to pack the steel in the annealing box with some substance that will exclude the air as much as possible. For this reason charcoal has not worked as well as other substances. Lime, if used as a packing material, insures a good anneal if the process is carried on properly; but appears to leave a heavy hard scale on the outside. Some claim good results from a mixture of lime and charcoal; this the writer has not tried because excellent results were obtained by packing the steel in dry clay in an annealing box, the cover being put in place and sealed, the box placed in the furnace and the steel heated to a yellow. It was allowed to cool as slowly as possible. The exact temperature necessary to heat the steel, in order to get satisfactory results depends somewhat on the steel used and also on the size of the piece. Smaller pieces do not require quite so much heat as larger ones, neither should they be subjected to heat for as great a length of time.

The following method is practised in a shop that an-

neals over a ton of high speed steel per day. This steel is of several makes and the method seems to apply equally well to any of them, and is as follows: The steel is packed in long pipes with a mixture of charcoal, lime, and cast iron chips in equal quanities. The steel is placed in the furnace in the morning and subjected to heat all day the temperature which as gauged by a pyrometer, is between 1,600 and 1,700 degrees. The steel is allowed to remain in the furnace all night and cool off with it. In the morning the tubes containing the steel are removed from the furnace, covered with hot ashes and allowed to cool as slowly as possible.

While this method appears to give excellent results, I have obtained best success with fire clay as a packing material; either material may be used over and over with good results.

The idea prevails among some mechanics that this steel after being hardened cannot be annealed and then hardened again. While I have never experimented along these lines with *all* the different makes I have with several of them, and found no trouble when the tool was repeatedly annealed and hardened. I could not detect any difference in the cutting qualities of the tool after it had been hardened four or five times.

One objection raised against this steel for tools to be used in the lathe or planer, where the tool was held in a tool post and thereby subjected to the breaking strain incident to the manner which it was held, is, that the steel broke in the tool post when heavy cuts were being taken. This trouble may be avoided by annealing the bar, or cutting it to proper lengths and annealing, after which the tool may be forged and hardened. It is not considered good practice to attempt to harden tools made from this

steel any where except on the cutting end, thus leaving the portion in the tool post sufficiently tough to resist the breaking action of the screw.

When annealing the steel for the purpose just mentioned above, it is not necessary to be as thorough as when it is to be worked with cutting tools, and it may be accomplished by heating the steel to a low yellow heat and burying in red hot ashes (or lime which has been thoroughly heated before the steel is placed in it), it is necessary to thoroughly protect it from the chilling effects of the air, or any material which is cold or damp.

In order to get satisfactory results in the hardened tool it is necessary after forging, to reheat the tool to a full red and allow it to cool off, thus relieving the strains incident to forging; when cool it may be reheated and hardened.

While the amount of heat necessary to insure best results when hardened steels of different makes cannot be stated arbitrarily, it is claimed for *most* of them that a *full red* heat should be employed when forging. However some makers claim best results for their steel if it is heated to a full yellow (above 1,850 degrees), at which temperature it is soft and easily worked. The forging proceeds until the temperature lowers to a good red, say 1,500 degrees, when work on the piece should cease and the steel reheated before forging is removed. It is, however, best to get instructions from makers of the steel, as to the temperature that insures best results, before doing any work on it.

In case of the smith who carefully observes the action of heat on steel I claim that he can, in a short time, find out more about the proper heat and method of working a given brand of this steel in order that the tools may

give satisfaction in the shop whose condition he understands, than it is possible for him to learn from any instructions the maker can furnish, because these instructions must of necessity be general and cannot apply to the varying conditions found in the individual shop. The careful smith will soon find out for himself at what heat the steel works best under the hammer. The heat should be one that allows the steel to work nicely. While the maker of some of these steels claim good results when it is placed in the hands of men who are not specially skillful in the manipulation of steel, I think I am safe in saying that when forging most brands, it is necessary to exercise greater caution than when forging *high carbon* steels, and every smith knows they are extremely sensitive.

If the steel is hammered when it is not hot enough the grain is fractured. If large pieces are being worked, the blows should be sufficiently heavy to cause the steel to flow as uniformly as possible; heavy blows with a heavy hammer should not be given a *light* section. The forging heat must be uniform, that is, the piece must be as nearly as possible of the same temperature at the center as the surface.

Blacksmiths are sometimes careless when working these steels, thinking that because high heats when hardening are essential to good results, any heat will do for forging. This is a great mistake as the steel is extremely sensitive but requires high heats when hardening to give it the desired cutting qualities.

A common mistake and one that has proved very costly to many concerns, consists in changing from a steel that has been giving satisfactory results for another whose only recommendation is that the representative shows testimonials from parties who have used it and

claim results way beyond what is being received from the brand they are using. In all probability the other parties are machining a stock entirely different in composition and as a consequence are able to get more work out of the tools.

The writer would not be understood as saying we should always "let well enough alone" and continue to use an inferior article while his competitor was getting the best and as a consequence is leaving him way in the rear. But many times parties have discarded one steel and adopted another which was no better and in doing so they have adopted a steel that required different treatment from the one they were using at first. The smith not realizing this fails to treat it properly and the results are not as satisfactory as with the first.

If steels of different makes are used they should be distinctly marked and the smith should be given explicit instructions for working each. Generally speaking, however, it is poor policy to have several makes of this steel around at the same time.

The operator should follow instructions accompanying the steel to the letter, unless experience has convinced him and all concerned that some other method of treatment is better adapted to their needs.

However the instructions given do not always instruct, and sometimes the men sent out by the steel concerns as demonstrators know less about the steel they represent than the smith whom they are supposed to teach. This does not necessarily prove that the steel is of no value.

The smiths who are the most successful in handling these steels are the ones who are ever on the lookout for knowledge, and learn all they possibly can of its nature,

and the treatment best adapted to the needs of the shop they are in.

I think most blacksmiths who have had an extensive experience working high speed steels prefer a fire of coke when heating for forging.

Heating for Forging.

We have been taught from the time we first hardened a piece of steel that *high* heats were to be avoided, that the *lower* the heat the more serviceable the tool, provided, of course, it was sufficiently high to accomplish what we desired. Now a steel is given us which requires a *full* white heat in order to give it a condition that insures doing what we expect of it. That is, *most* makes of this steel require the high heat mentioned. If the tools to be hardened are of a form that are not injured by scaling they may be heated in an open fire in an ordinary blacksmith's forge. If, however, taps, reamers, milling machine cutters, or any form which would be injured by scaling are to be hardened, they must be heated in a gas or other furnace especially made for high heats, or in a crucible of lead heated to the proper temperature. The lead being at a very high temperature the surface has a tendency to oxidize very rapidly; this can be prevented somewhat by placing powdered charcoal on the top, which must, of course, be renewed frequently.

A very satisfactory method of heating specially formed tools of high speed steel, such as taps, dies, milling cutters, reamers and similar tools, is a muffle furnace of special design, heated by oil or gas. This furnace has two chambers one above the other. The lower chamber may be heated to a temperature of 2,200 degrees Fahr., and

the temperature maintained uniformly, while the upper chamber is not heated nearly as hot. The tools may be slowly heated by placing on top of the furnace in a temperature that does away with the tendency to crack when they are subjected to a higher heat. While in the upper chamber they can be brought to a red heat. It is now safe to place them in the lower chamber and allow them to remain until they are of the proper temperature for hardening.

When electric current is available an excellent method of heating may be had that is rapid, reliable and easily controlled. The description of this method is taken from

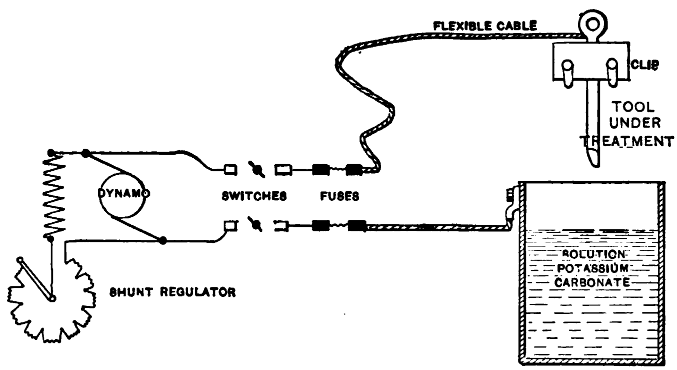


Figure 163. Apparatus for hardening tools electrically in a bath of potassium carbonate.

the abstract of paper read by Mr. J. M. Gledhill previously referred to. A brief description of this kind of heating may be of interest.

One method adopted for electrically heating the points of tools, and the arrangement of apparatus is shown in accompanying cut, Fig. 163. It consists of a cast-iron

tank of suitable dimensions, containing a strong solution of potassium carbonate, together with a dynamo, the positive cable from which is connected to the metal clip holding the tool to be heated, while the negative cable is connected direct on the tank. The tool to be hardened is held in a suitable clip to insure good contact. Proceeding to harden the tool the action is as follows:

The current is first switched on and then the tool is gently lowered into the solution to such a depth as is required to harden it. The act of dipping the tool into the alkaline solution completes the electric circuit and at once sets up intense heat on the immersed part. When it is seen that the tool is sufficiently heated the current is instantly switched off, and the solution then serves to rapidly chill and harden the point of the tool, so that no air blast is necessary.

If it is necessary to heat in an ordinary forge when hardening lathe, planer and similar tools, the point *only* of which needs hardening, a good large fire of well coked coal may be used, making sure that the fire is large enough so that no air from the blast inlet will strike the heated portion. When the desired heat has been obtained the tool is then held in a strong air blast of generous proportions. Best results are obtained if the point of the tool is held several inches away from the nozzle of the blast pipe. If an air blast is not available, dip the point of the tool in oil, raw linseed, cotton seed oil, or almost any fish oil will answer.

After hardening the tool may be ground to shape, and it is ready for use, unless projecting portions or light sections necessitate drawing the temper to insure sufficient strength. The object attained in drawing the temper is that the brittleness is reduced so the tool will not break

when subjected to shock and strain incident to cutting. When the temper has been drawn the desired amount, lay the tool to one side and allow it to cool slowly where no current of air can strike it. Do not quench it when the proper temperature is reached for while it is safe to plunge certain shapes of tools made from this steel in *hot* water when at a high heat, it is not safe to quench them at tempering heats.

If such tools as milling machine cutters, taps, reamers and similar tools are to be heated for hardening, it is necessary to remove them from the oxydizing action of the air when at the high heat. To accomplish this they may be heated in specially constructed furnaces as previously described, or in a crucible of lead. The furnace described is so designed that there are three steps in the heating operation; first the cold cutter is placed on top and heated somewhat, so it is possible to subject it to a red heat without cracking it as would be the case if the cold steel were subjected to the red heat. After becoming heated somewhat it is placed in the upper chamber where it is gradually heated to a full red heat; it is then placed in the lower chamber and heated to the proper temperature to insure desired results.

If the furnace used has but one chamber it is necessary to heat the tool to a red in an open fire or where it may be heated slowly; it may then be placed in the furnace and given the desired temperature.

Now, while a crucible of lead is many times used to heat tools made from high speed steels for hardening, its use as a *permanent* means of heating is hardly to be advocated as the lead oxidizes very rapidly and the fumes are poisonous. For the same reason that it would not do to place a cold tool in the chamber of the furnace, it is nec-

essary to heat articles red hot before plunging in lead heated to a white heat. If the tool was immersed when cold into lead heated to the temperature mentioned it would spring or crack from the sudden expansion of the outer surface of the steel. The tool should be allowed to remain in the lead just long enough to insure a *uniform* heat of the proper temperature.

If comparatively large tools are to be heated in the lead, the crucible should be of generous proportions, or the contents will be cooled so much by immersion of the steel that the temperature will be lowered to a point that will necessitate reheating to bring it to the high heat required.

At times the operator is deceived as to the proper heat by attempting to get heats that insure a hardened surface that cannot be touched with a fire. The steel may be so hard, a file will have no impression on it and yet fail to give satisfactory results. Again, tools which are hardened at the temperature necessary to give this, may leave the temperature drawn until they file readily and still stand up nicely when tested at high speeds and heavy cuts. The intense heat is necessary to bring about certain chemical changes necessary to give desired results.

When the tool is heated to the required temperature it may be plunged in a bath of raw linseed, cotton-seed, or fish oil, and allowed to remain until cool. If it is an end mill, excellent results are many times obtained by quenching in boiling water, or hot brine. It is necessary to remember, however, that only the portion heated to a white may be put in water, or the part which is not so hot is liable to crack.

The writer's experience in hardening taps does not warrant his advising the use of lead as a heating medium

for them; and he has seen the representatives of steel concerns selling this steel have repeated poor success when trying it. Probably the most satisfactory method is to heat in specially prepared furnaces, but such furnaces are not always available, and excellent results may be obtained by placing the tap in a piece of gas pipe closed at one end, a quantity of finely broken charcoal or coke (the writer prefers coke) may be placed in the tube and the remaining end sealed. The tube may now be heated to the desired temperature, the top removed and plunged in oil. It will be necessary to draw the temper of tools having slender teeth, this drawing is nicely done in heated sand. The amount necessary to draw the temper will depend on the use to which it is to be placed, it may be a straw, brown, or blue color, or in cases requiring freedom from brittleness the tool may be heated until a dull red shows when it is held in a shaded place, as in a barrel or keg.

When pieces have been heated for tempering, place them where no dampness or current of air can strike them, and allow them to cool off.

In the case of taps it will be found advisable to heat the shanks red hot in red hot lead, then place the *shank* in lime to cool off as slowly as possible; this may be done after drawing the temper of the cutting end.

Some mechanics using this steel, object to drawing temper, saying it should be as hard as it can be made. However, if we attain to anything like the speeds claimed for the steel, it is very quickly heated to a temperature even higher than the temper heats mentioned, so it is obvious that drawing temper for toughness can not seriously detract from its *staying* qualities and it is certainly necessary when parts that are weak are to be subjected to great strain.

Speeds and feeds.

Experience has convinced the writer that it is a mistake, generally speaking, to grind lathe, planer and similar tools on a *wet* emery wheel, as it requires considerable pressure of the tool on the wheel to insure its cutting, this pressure is, of course, productive of heat, the water striking the heated steel causes it to crack; especially are the above results noticeable if the grinding is done by men *not* extremely careful.

Best results follow grinding on a free cutting *dry* wheel, after which it may be finished on a free cutting grind stone.

Speeds and Feeds.

As previously stated the speed at which these steels can be used with satisfactory results depends in a great measure on the condition of the stock being machined. Many times the depth of chip and the rate of feed are entirely overlooked and as a consequence less stock is removed than if the machine was run somewhat slower and heavier cuts and coarser feeds used.

It is necessary, however, in order to have something tangible, that we have before us results of tests made with stock of various kinds and as the writer has never kept a record of results obtained in his experiments it has seemed wise to give results claimed by the makers of certain brands of this steel. The reader need not be discouraged if he is not able to duplicate the results given in the table, and yet under certain conditions he may be able to do even better.

One maker claims, that when turning bars of hard steel the stock was run at a rate of 160 feet per minute,

the depth of cut 3/4 inch, the feed 1-32 inch, the amount of stock removed in a day of 10 hours being about 2,500 pounds, the cutting tool being ground but once a day.

Another maker claims that twist drills made from their steel would stand from two to four times the speed of the best carbon steel, and even at the high speed would drill from 6 to 25 times as many holes before it required grinding.

He also claimed that taps made from their steel would stand three or four times the speed of regular tool steel taps, and stood up 40 to 50 times as long.

Reamers from the same steel it is claimed, were run at twice the speed of those made from ordinary carbon steel and showed an efficiency of 15 to 1.

Milling machine cutters made from another make of this steel were run at a rate of 150 feet per minute on mild open hearth steel, as compared to 28 feet per minute with a similar cutter made from regular tool steel.

Experiments in cutting cast iron in the lathe showed that a speed of from two to four times that possible when tools made from carbon steels, was used.

Hardening and Tempering Rock Drills

Drills used in drilling rock are used under vastly differing conditions, and are not all treated alike. The success of a drill depends in a large measure on the steel used, in its construction and in the treatment it receives when it is forged. As the sharpener has constant practice and his whole time is devoted to this one line of work he becomes very skillful and, while he works quite rapidly, he is extremely careful when heating and forging.

The shape of the drill has nearly as much to do with

ability to stand up as the method employed in hardening, so the sharpener should find the shape that gives best results and then stick to it as closely as possible.

The sharpening should be done at low heats and blows should be lighter as the steel cools, to prevent crushing the grain.

The heat for hardening should be the *refining* heat for the particular steel being used.

A bath of brine made by dissolving all the salt it will take in a tank or barrel of rain-water, is the one commonly used, although some sharpeners add other ingredients.

The hardening generally extends from 1 inch to 1¼ inches up from the point, the steel being heated higher up contains sufficient heat to draw the temper the desired amount.

The treatment of the steel during forging and hardening has a great deal to do with the amount it is "let down" in tempering. If the heats were low the steel will be strong and the temper may be left high; if the heats were high the steel will be brittle and the temper must be drawn considerable. We will assume, however, that the heats have been carefully gauged for both forging and hardening.

For most steels that have come under the observation of the writer, the temper should be drawn to the faintest color visible, that is, when the temper color commences to show, the drill should be checked in oil; under certain conditions, however, the temper is drawn to a light straw color.

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